REPORT

DRAFT FOR STATE AND FEDERAL REVIEW

Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site RI/FS

Remedial Investigation Report - Phase I

Volume 1 of 2

Allied Paper, Inc./Portage Creek/
Kalamazoo River Superfund Site
Kalamazoo and Allegan Counties,
Michigan

October 2000

BBL
BLASLAND, BOUCK & LEE, INC.
engineers & scientists

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Note: After review and final acceptance of this document, the Disclaimer will read as follows:

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Table of Contents

Tables

Figures

Appendices

Acronyms and Abbreviations

ABSA	aquatic biota sampling area
AChE	acetylclolinesterase
Allied OU	Allied Paper, Inc. Operable Unit
AOC	Administrative Order by Consent
ARARs	applicable or relevant and appropriate requirements
ATSDR	Agency for Toxic Substances and Disease Registry
BAF	Bioaccumulation factor
BBEPC	Blasland & Bouck Engineers, P.C.
BBL	Blasland, Bouck & Lee, Inc.
^{7}Be	Beryllium^{7}
bgs	below ground surface
BSAF	biota sediment accumulation factor
BSP	Biota Sampling Plan
°C	degrees Celsius
C	PCB concentration in the mixed layer
C_i	PCB concentration on depositing sediment
CDM	Camp Dresser & McKee, Inc.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cfs	cubic feet per second
CLP	Contract Laboratory Program
^{137}Cs	Cesium^{137}
CV	coefficient of variation
cy	cubic yards
DCB	decachlorobiphenyl
DCS	Description of the Current Situation
DMP	Data Management Plan
DO	dissolved oxygen
DOC	dissolved organic carbon
EFF	engine fuel factor
EE/CA	Engineering Evaluation/Cost Analysis
EFCM	East Foundry Cove Marsh
EPCs	exposure point concentrations
ERA	Ecological Risk Assessment
°F	degrees Fahrenheit
FFS	Focused Feasibility Study
FINDS	Facilities Index Data System
FM	frequency modulation
FML	flexible membrane liner
FOIA	Freedom of Information Act
fps	feet per second
FS	Feasibility Study
FSP	Field Sampling Plan
Georgia-Pacific	Georgia-Pacific Corporation
Giesy	Giesy Ecotoxicology, Inc.
GLEAS	Great Lakes Environmental Assessment Section
GLNPO	Great Lakes National Program Office

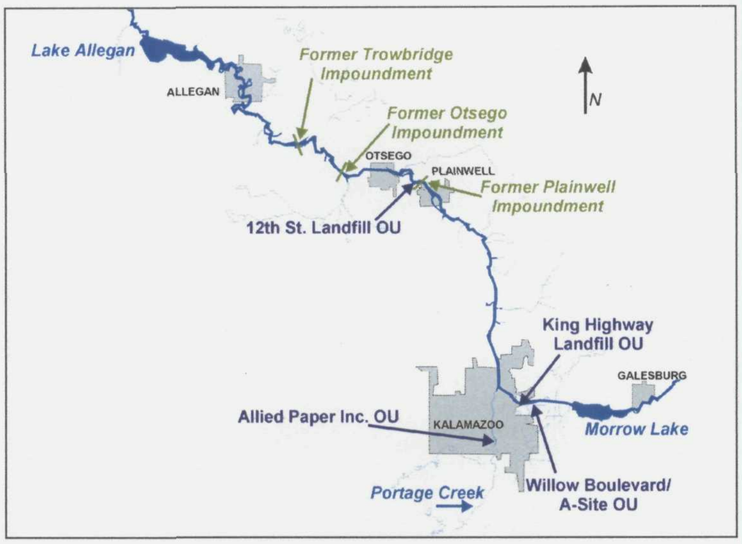
GLSFATF	Great Lakes States Fish Advisory Task Force
GPR	ground penetrating radar
GPS	global positioning system
GRA	General Response Action
GSI	Groundwater/Surface Water Interface
HASP	Health and Safety Plan
HDPE	high density polyethylene
HHRA	Human Health Risk Assessment
HP	horsepower
HPV	health protective value
HRDL	Historic Residuals Dewatering Lagoon
HSI	habitat suitability index
HQ	hazard quotient
IJC	International Joint Commission
IRM	interim response measure
JSA	Arcadis JSA
K	fish condition factor
KALSIM	Kalamazoo River PCB Simulation Model
kg	kilogram
kg/yr	kilogram per year
KHL-OU	King Highway Landfill Operable Unit
kHz	kilohertz
K_{ow}	octanol-water partition coefficient
KRSG	Kalamazoo River Study Group
KRWC	Kalamazoo River Watershed Council
KSSS	King Street storm sewer
KWRP	Kalamazoo Water Reclamation Plant
LMMBS	Lake Michigan Mass Balance Study
LTI	Limno-Tech, Inc.
MDCH	Michigan Department of Community Health
MDEQ	Michigan Department of Environmental Quality
MDL	method detection limit
MDNR	Michigan Department of Natural Resources
MDPH	Michigan Department of Public Health
mg/kg	milligram per kilogram
mg/L	milligram per liter
MHI	Millennium Holdings, Inc.
MHz	megahertz
mi^2	square miles
mL	milliliter
MNFI	Michigan Natural Features Inventory
MIRIS	Michigan Resource Information System
Monsanto	Monsanto Industrial Chemicals Company
MS	matrix spike
MSD	matrix spike duplicate
MSL	mean sea level
MSU	Michigan State University
MWRC	Michigan Water Resources Commission
NCDC	National Climatic Data Center
NCP	National Oil and Hazardous Substances Pollution Contingency Plan

ng/kg	nanogram per kilogram
ng/L	nanogram per liter
NGVD	National Geodetic Vertical Datum
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NRC	National Research Council
NRD	natural resource damage
NREPA	Natural Resources and Environmental Protection Act
NWI	National Wetlands Inventory
NYSDEC	New York State Department of Environmental Conservation
ODEQ	Oregon Department of Environmental Quality
OME	Ontario Ministry of the Environment
OSI	Ocean Surveys Inc.
OU	Operable Unit
p	statistical significance level
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl(s)
PCDD/PCDF	polychlorinated dibenzodioxins and dibenzofurans
POC	particulate organic carbon
POLREP	Pollution Report
POTW	publicly owned treatment works
ppb	part per billion
ppm	parts per million
PRP	potentially responsible party
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
r^2	coefficient of determination
RD/RA	remedial design/remedial action
residuals	paper-making residuals
RI	Remedial Investigation
RI Report	Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site Remedial Investigation Report
ROD	Record of Decision
RPD	relative percent difference
RRO	remedial response objective
S	deposition rate
SARA	Superfund Amendments and Reauthorization Act
SDG	sample delivery group
SIC	Standard Industrial Classification
Site	Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site
SMU	Sediment Management Unit
SOP	standard operating procedure
SOW	Statement of Work
STL	Severn Trent Laboratories
SVOCs	semivolatile organic compounds
SWAC	surface area weighted average concentration
SWQD	Surface Water Quality Division
t	student's t statistic
TBC	To Be Considered
TBSA	terrestrial biota sampling area

TCDD	tetrachlorinated dibenzo-p-dioxins
TCE	trichloroethene
TCL/TAL	Target Compound List/Target Analyte List
TCMX	tetrachloro-meta-xylene
TEF	toxicity equivalency factor
TOC	total organic carbon
TRI	Toxic Release Inventory
TSS	total suspended solids
UCSB	University of California at Santa Barbara
UM	University of Michigan
USACE	United States Army Corps of Engineers
USCS	United Soil Classification System
USDA-SCS	United States Department of Agriculture Soil Conservation Service
USDOT	United States Department of Transportation
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
USFHA	United States Federal Highway Administration
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VOCs	volatile organic compounds
W	Shapiro – Francia Test Statistic
WB/A-OU	Willow Boulevard/A-Site Operable Unit
WET	Wetland Evaluation Technique
WDNR	Wisconsin Department of Natural Resources
WMU	Western Michigan University
WTF	water treatment facility
w/w	wet weight
Z_m	thickness of the mixed layer
µg/kg/day	micrograms per kilogram per day
µg/L	microgram per liter
µg/m^3	microgram per cubic meter

Section 1

Inside Section 1 – Introduction



The Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site

Purpose of the Remedial Investigation Report:

- Characterize the Site and the actual or potential hazards to public health and the environment
- Gather data to support risk assessments and the detailed evaluation of alternatives in the Feasibility Study

What are PCB?

PCB, or polychlorinated biphenyls, are a group of chemical compounds in which one to ten chlorine atoms are attached to a biphenyl molecule. Although the manufacture of PCB was banned in the late 1970s, they remain persistent environmental pollutants that bioaccumulate in fish and, therefore, may pose risks to humans and other consumers of fish.

How did PCB get into the river?

Sources of PCB to the Kalamazoo River included a variety of local industries that used or handled PCB-containing products, including paper manufacturing facilities that recycled paper between the late 1950s and early 1970s. The PCB in the paper recycled during this period came from the use of PCB in carbonless copy paper manufactured outside of the Kalamazoo River Basin.

Why set up Operable Units?

The four "OUs" or Operable Units identified in the map above had been used as disposal sites for paper-making residuals and were considered to be potential sources of PCB to the Kalamazoo River and Portage Creek. The OUs were established to allow for remediation of these areas on a schedule independent of the river work.

PCB are persistent environmental pollutants and are the constituent of concern in the Kalamazoo River.

1. Introduction

1.1 Purpose and Goals

This draft report presents the findings of environmental investigations of the Allied Paper, Inc./Portage Creek/ Kalamazoo River Superfund Site (the Site), located in Kalamazoo and Allegan counties, Michigan. Blasland, Bouck & Lee, Inc. (BBL) and others have prepared this report on behalf of the Kalamazoo River Study Group (KRSG), which is composed of Millennium Holdings, Inc. (MHI), Georgia-Pacific Corporation (Georgia-Pacific), Fort James Corporation, and Plainwell, Inc.

The Remedial Investigation (RI) has been conducted pursuant to an Administrative Order by Consent (AOC) (Final Order No. DFO-ERD-91-001) issued by the Michigan Department of Natural Resources[1] (MDNR) (MDNR, 1991). The purpose of the RI is to characterize the Site and the actual or potential hazards to public health and the environment, and to collect and analyze data sufficient to support the detailed evaluation of alternatives in the Feasibility Study (FS).

As stated in the AOC, the goals of the RI are to:

- Characterize the chemical nature of wastes at the Site;
- Define identifiable contaminant sources at the Site;
- Determine the vertical and horizontal extent of contamination at the Site;
- Spatially quantify contamination to the extent necessary to enable preparation of a Risk Assessment and an FS;

> **Section Summary**
>
> The purpose of this Remedial Investigation (RI) report is to characterize the Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site (the Site) and the actual or potential hazards to public health and the environment. The RI report:
>
> - Characterizes the chemical nature of wastes at the Site;
> - Identifies contaminant sources;
> - Determines the vertical and horizontal extent of contamination;
> - Quantifies contamination to the extent necessary to *prepare a Risk Assessment and Feasibility Study*;
> - Identifies contaminant migration pathways; and
> - Quantifies public health and environmental risk.
>
> The total area investigated encompasses the Kalamazoo River from Morrow Lake to Lake Michigan, and Portage Creek from Alcott Street to the Kalamazoo River.
>
> From Morrow Lake to the mouth of the river at Saugatuck, the Kalamazoo River is an alternating series of free-flowing sections and impoundments formed by seven low-level dams. The former Plainwell, Otsego, and Trowbridge dams, which are owned by the Michigan Department of Natural Resources (MDNR), were partially dismantled by the MDNR to their sill levels; however, they still impound some water and sediment.
>
> Water quality in the Kalamazoo River was recognized as a problem as far back as the 1930s. A variety of industries and municipal sewage treatment plants have operated along the banks of the river and many discharged wastewater or waste products directly to the river with little or no treatment. From 1957 to 1971, certain carbonless copy paper containing polychlorinated biphenyls (PCB) was manufactured. Recycling paper, such as office paper that included this carbonless copy paper, produced a waste stream containing PCB.

[1] In October 1995, the environmental quality divisions were split from the MDNR and placed in the newly created Michigan Department of Environmental Quality (MDEQ).

- Identify contaminant migration pathways and movement; and
- Quantify public health and environmental risk.

The Remedial Investigation/Feasibility Study (RI/FS) has been conducted in accordance with the AOC and is consistent with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR Part 300, Subpart E). the Michigan Natural Resources and Environmental Protection Act (NREPA; Act 451, Part 201), and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1996.

The RI/FS is being completed in accordance with various management plans developed under the AOC Statement of Work (SOW) and as approved by the MDNR/Michigan Department of Environmental Quality (MDEQ). These plans include:

- *Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site Remedial Investigation/Feasibility Study Work Plan* (RI/FS Work Plan) (Blasland & Bouck Engineers, P.C. [BBEPC], 1993f) and addenda (Brown, 1995a; 1995b; 1996a; BBL, 1997);
- *Field Sampling Plan* (FSP) (BBEPC, 1993g);
- *Quality Assurance Project Plan* (QAPP) (BBEPC, 1993a);
- *Health and Safety Plan* (HASP) (BBEPC, 1993b);
- *Quality Assurance/Quality Control Review of Historical Data and Studies Plan* (BBEPC, 1993c);
- *Data Management Plan* (DMP) (BBEPC, 1993d); and
- *Plan for Satisfaction of Permitting Requirements* (BBEPC, 1993e).

After completion of the initial RI/FS Work Plan in 1993 (BBEPC, 1993f), the KRSG performed the majority of the RI field efforts by 1994. Supporting documents were then completed and approved by the MDNR/MDEQ. Since that time, numerous additional soil and sediment core analyses have been performed, and follow-up fish and surface water monitoring conducted. Unless otherwise noted, additional field work, sampling, and analyses have been performed under several addenda to the initial Work Plan in a manner consistent with the objectives and methods set forth in the FSP, QAPP, and the other management plans listed above.

This RI report summarizes and incorporates by reference the contents, results, and findings of various technical memoranda and draft technical memoranda relevant to Kalamazoo River and Portage Creek sediments, surface water, floodplain soils, and biota that were previously submitted to the MDNR/MDEQ (see box). Numerous additional reports and documents have been prepared for the four operable units (OUs) and related mill properties located near or adjacent to the river. The technical memoranda and other RI/FS documents are available at the six information repositories established for the Site (i.e., local public libraries) or by contacting the MDEQ.

Technical Memoranda for Related Investigations

- *Technical Memorandum 1 - Mill Investigations/ Proposed Stormwater Sediment Sampling Locations (BBL, 1994a);*
- *Technical Memorandum 2 - Results of Phase 1 Terrestrial Biota Sampling Area (TBSA) Soil Sampling (BBL, 1994b);*
- *Addendum to Technical Memorandum 2 - Results of Phase 2 Terrestrial Biota Sampling Area Soil Sampling (BBL, 2000d);*
- *Technical Memorandum 3 - Results of the Floodplain Soils Investigation (BBL, 1994c);*
- *Addendum 1 to Technical Memorandum 3 - Supplemental Floodplain Soils Investigation (Portage Creek) (BBL, 1996e);*
- *Draft Technical Memorandum 10 - Sediment Characterization/Geostatistical Pilot Study (BBL, 1994e);*
- *Draft Technical Memorandum 12 - Former Impoundment Sediment Investigation (BBL, 1994d);*
- *Technical Memorandum 13 - Water Well Inventory (BBL, 1995b);*
- *Draft Technical Memorandum 14 - Biota Investigation (BBL, 1994f);*
- *Draft Addendum 1 to Draft Technical Memorandum 14 - Biota Investigation (BBL, 1994g);*
- *Draft Addendum 2 to Draft Technical Memorandum 14 - Biota Investigation (BBL, 1995c);*
- *Draft Addendum 3 to Draft Technical Memorandum 14 - Biota Investigation (BBL, 1998);*
- *Technical Memorandum 15 - Mill Investigations (BBL, 1996a); and*
- *Draft Technical Memorandum 16 - Surface Water Investigation (BBL, 1995a).*

For ease of review, this report is organized into seven sections. The rest of Section 1 provides the history and description of the Site. The various Site investigations are summarized in Section 2. The physical characteristics at the Site, including descriptions of the area's ecology and demography, are outlined in Section 3. Section 4 contains an analysis of the nature and extent of contamination at the Site, focusing on polychlorinated biphenyls (PCB) concentrations in sediment, floodplain soils, exposed sediment, surface water, and biota. In Section 5, the factors affecting fate and transport of PCB and an assessment of the conditions in the Kalamazoo River are described. Section 6 provides an overview of the ecological and human health risk assessments that have been conducted for the Site. Section 7 presents the proposed remedial response objectives and a conceptual site model, which concisely summarizes the overall conditions and trends identified during the RI and sets forth a basis for development of remedial alternatives in the FS. Further detail and associated data for several topics are contained in the various appendices.

1.2 Additional Information is Available

Additional data on studies pertaining to the sources, distribution, transport, fate, effects, and remediation of PCB in the Kalamazoo River are presented in the accompanying document titled *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). The studies are part of a program undertaken during 1999 to fill important and substantial gaps in our knowledge about PCB in the Kalamazoo River. The program was first proposed to the MDEQ on September 7, 1999 (Brown, 1999).

> **Why More Data?**
> The benefits of additional fish sampling became apparent in 1999. The Michigan Department of Community Health's study of Kalamazoo River anglers revealed that in addition to smallmouth bass, anglers were fishing for panfish, pike, walleye, and catfish. While the RI had collected smallmouth bass and a few walleye, the other species had not been sampled at all. Panfish, walleye, pike, smallmouth bass, and carp have been collected and analyzed using the same methods as those of the RI/FS Work Plan. The results cannot be either presented or discussed in this document; but are presented and discussed in the accompanying document titled *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

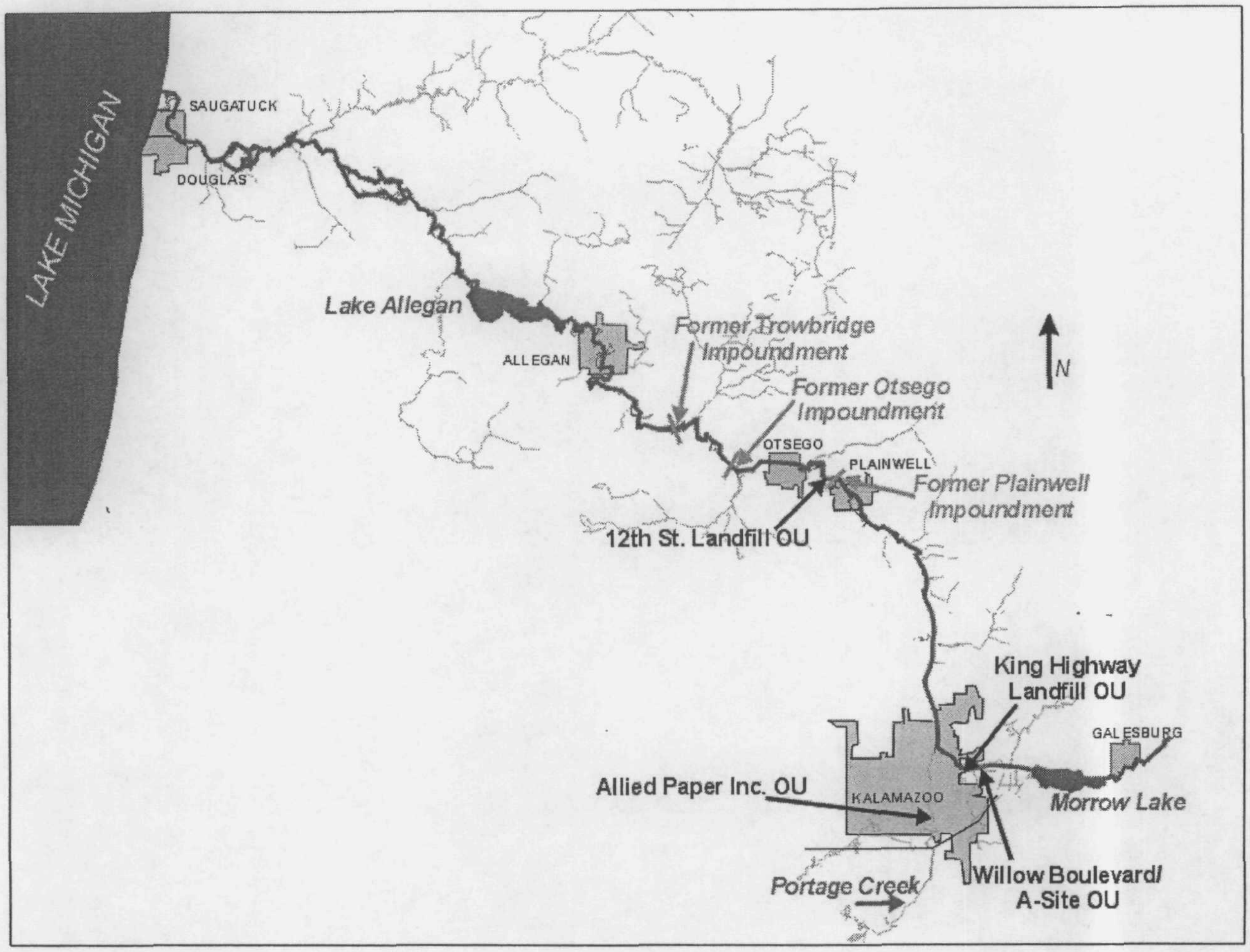
This has not been documented

At this time, the MDEQ has directed the KRSG to exclude this information and its interpretation from the RI/FS. explain why However, the MDEQ has allowed this draft RI/FS to refer to the results in the accompanying document, and the MDEQ has agreed to review and evaluate this additional information. At a number of locations within the RI/FS, the reader is advised of this pertinent information available in the accompanying Supplement.

1.3 Site Background

The total area investigated for this RI/FS encompasses the Kalamazoo River from Morrow Lake to Lake Michigan, and Portage Creek from Alcott Street to the Kalamazoo River (the Site[2]; see map below and Figures 1-1 through 1-13). Certain samples were also collected upstream of the Site in the vicinity of Battle Creek to characterize background concentrations of PCB. This RI report discusses conditions in the upper river upstream of Lake Allegan Dam; a separate RI report is being prepared for the lower river between Lake Allegan Dam and Lake Michigan. The *Description of the Current Situation* (DCS) report (BBEPC, 1992) provides additional background information on the Site.

[2] The area investigated extends beyond the boundaries of the site defined in the National Priority List (NPL). The NPL-defined site is 35 miles of the Kalamazoo River from Portage Creek to the Allegan City Dam and the lower three miles of Portage Creek.



Four separate areas adjacent to the Kalamazoo River or Portage Creek were designated as OUs. These areas had been used as disposal sites for paper-making residuals (residuals) and were considered to be potential continuing sources of PCB to the river and creek. The OUs were established to allow the RI/FS, and other response activities (i.e., remediation) to proceed on a schedule separate from the remediation plans for the rest of the Kalamazoo River. Response activities at the OUs are summarized in Section 4.7.1 and described in the individual RI/FS documents developed for each OU. The OUs are:

- Allied Paper, Inc. OU (Allied OU), including former Bryant Mill Pond (Figure 1-14);
- King Highway Landfill OU (KHL-OU) (Figure 1-15);
- Willow Boulevard/A-Site OU (WB/A-OU) (Figure 1-16); and
- 12th Street Landfill OU (Figure 1-17).

The river is also an International Joint Commission (IJC) Area of Concern, which means it is a specific geographic area exhibiting evidence of certain impairments of water, fish and wildlife, habitat, or aesthetic values of the resource. A total of 43 Areas of Concern in the Great Lakes Basin of the United States and Canada were identified by the IJC under amendments to the Great Lakes Water Quality Agreement of 1978 (IJC, 1987). The Kalamazoo River Area of Concern includes the lower portion of the watershed from Morrow Dam to the mouth of the river at Lake Michigan (Kalamazoo River Watershed Council [KRWC], 1998).

Both the NPL Site scoring package (Wallace, 1987) and the 1991 *Preliminary Public Health Assessment* issued by the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) listed PCB as the constituent of concern at the Site. PCB are a family of 209 compounds, referred to individually as "congeners," that differ in the number and arrangement of chlorine atoms on the biphenyl molecule. In the United States, PCB were produced as mixtures of PCB congeners for commercial purposes exclusively by Monsanto Industrial Chemicals Company (Monsanto) under the trade name Aroclor. PCB were widely used to insulate and transfer heat in electrical systems. Although most PCB produced in the United States were used in electrical component manufacturing, they also were used in other applications, including hydraulic fluids, cutting oils, heat transfer fluids, quench oils, and, from 1957 through 1971, PCB were used in the manufacture of carbonless copy paper.

PCB have entered the Kalamazoo River by numerous routes including direct discharge (e.g., wastewater effluent), indirect discharge through publicly owned treatment works (POTWs), and non-point-source runoff from upland areas. Sources that contributed PCB to the river included paper manufacturing facilities that recycled paper between the late 1950s and early 1970s, and a variety of other industries that used PCB products.

The KRSG are current or former owners of some of the paper recycling facilities that existed in the Kalamazoo River watershed. Although carbonless copy paper was not manufactured in the Kalamazoo River basin, it was shipped to the area mixed with other office paper destined for recycling at the KRSG mills. The paper recycling process produced a waste stream containing PCB. At that time, government wastewater discharge regulations were focused on improving water clarity and levels of dissolved oxygen (DO) in the Kalamazoo River, and the potential hazards of PCB were not generally recognized or well understood by either scientists or regulators.

PCB issues are a relatively recent chapter in a long history of water quality considerations in the Kalamazoo River, a history that extends as far back as the 1930s. A variety of industries and municipal sewage treatment plants have operated along the banks of the river for years, discharging wastewater or waste products directly to the river at times with little or no treatment. As a result, the river has experienced excessive variations of DO and pH; reduced DO levels; excessive plant nutrient levels; and elevated levels of total mercury, phenols, bacterial levels, and un-ionized ammonia (Beck and Buda, 1978). By 1975, the Great Lakes Basin Commission reported that pollution loads entering the river had declined and water quality had substantially improved. These improvements in water quality were thought to be primarily a result of the water pollution control measures implemented by paper mills, other local industries, and municipalities both before and after passage of the 1972 federal Clean Water Act and related laws and regulations.

> ➢ Swimming, boating, and other river activities do not pose health risks.

Over the past 25 years. water quality has improved significantly. As a result, recreational activities such as swimming, boating, or wading have increased. Exposure to PCB through these activities does not cause a health risk. The Michigan Department of Community Health (MDCH, formerly the Michigan Department of Public Health [MDPH]) reports in its 1996 Kalamazoo River Fishing and Recreation Guide that "there are PCBs in the mud on the bottom of the Kalamazoo River and Portage Creek. Very little of the PCBs in the mud can get past your skin and into your body. Being exposed to river mud or water by accidentally ingesting it is very unlikely to cause health problems. So you can enjoy recreational activities on the river like boating, canoeing, tubing, and swimming." Similarly, the Human Health Risk Assessment performed for the Site by MDEQ's consultant (Camp Dresser & McKee, Inc. [CDM], 2000b) indicates that, "[t]he significance of exposures to in-stream sediment and surface water is considered low due to the relatively low surface water and sediment ingestion rates associated with swimming and wading, the low solubility of PCBs in water, and limited absorption through the skin."

> **Fish consumption is the primary concern...**
>
> ➢ Fish tissue PCB concentrations have been decreasing to levels that presently allow for significant relaxation of current fish consumption advisories.

The only significant PCB exposure pathway for humans at the Site is the consumption of fish. A survey of Kalamazoo River anglers and recent fish data both indicate that this is a pathway of diminishing importance. A 1994 survey of Kalamazoo River anglers conducted by the ATSDR (ATSDR, 2000) found no elevation in PCB blood levels in those who ate Kalamazoo River fish other than that attributable to age (see Section 6.1 for more information). In addition, as explained in Section 5.2.3 and Appendix A, recent fish monitoring data (1993 and 1997) indicate that fish tissue PCB concentrations have been decreasing to levels that presently allow for significant relaxation of current fish consumption advisories. Nevertheless, using standard risk assessment assumptions, the MDEQ has estimated risks to consumers.

1.4 Site Description

> ➢ **Between Morrow Lake and Lake Michigan, the Kalamazoo River is impounded by 7 dams and fed by 12 tributaries.**

Between Morrow Dam and the mouth of the river at Saugatuck, the Kalamazoo River is an alternating series of free-flowing sections and impoundments formed by low-level dams. From upstream to downstream, the dams are Morrow Dam, former Plainwell Dam, Otsego City Dam (also known as the Menasha Dam), former Otsego Dam, former Trowbridge Dam, Allegan City Dam (also known as the Imperial Carving Dam), and Lake Allegan Dam (also known as the Calkins Dam). The former Plainwell, Otsego, and Trowbridge dams, which are owned by the MDNR, were permanently opened by the MDNR and the impoundments drawn down to their sill levels in the early 1970s. In 1987 the MDNR removed these dams down to their sills, which still impound some water and sediment. The Lake Allegan Dam is owned by Consumers Energy and is actively used to generate electric power. The river is still impounded by the Otsego City and Allegan City dams; however, they no longer generate power. There are 12 tributaries flowing into the river -- the largest is the Rabbit River, which discharges to the Kalamazoo River near the Village of New Richmond. Swan Creek, another relatively large tributary, enters the Kalamazoo River at the Swan Creek Marsh, within the Allegan State Game Area. Both of these tributaries enter the Kalamazoo River downstream of Lake Allegan.

The drawdown of the three MDNR-owned impoundments in the early 1970s had a significant effect on the existing distribution of PCB in the river. By lowering water levels in the impoundments, the river was forced to carve a new channel through the impoundment sediment, thereby redistributing thousands of cubic yards of sediment and several tons of PCB that had been sequestered in the sediment bed of the former impoundments in the downstream reaches of the river. The natural river channel has not been completely reinstated, and hydraulic heads of approximately 5 to 10 feet exist. After the drawdown of these impoundments, sediments that were once covered by the water column were exposed and now comprise floodplains in these areas. The continuing changes in channel shape and position within the former impoundments are evident by the sloughing and erosion of the steep banks that were rapidly created as a result of the drawdowns. The three MDNR-owned dams were inspected in 1995 and 1996 by the MDNR and again in 1999 by CDM. All three received a high-hazard-potential classification due to their crumbling structures and unsafe conditions (Hayes, 1995a, 1995b, 1995c, 1996a, 1996b, 1996c; CDM, 1999a, 1999b, 1999c). The dams are currently owned by the Wildlife Division of the MDNR and are operated by a representative of the Allegan State Game Area.

Plain and Otsego townships. According to the MDNR, stages higher than 707.0 feet above mean sea level (MSL) will result in flowing water passing over portions of the embankment adjacent to the spillway and the former powerhouse. Spillway capacity at 707 feet above MSL is about 5,700 cubic feet per second (cfs), which approximates the 10-year flood stage (Hayes, 1996b).

Plainwell Dam to Otsego City Dam. The 1.7 miles of the river from Plainwell Dam to Otsego City Dam covers approximately 96 acres (Appendix B) and has an average width of approximately 450 feet and average depth of approximately 2.5 feet (BBL, 1994e). For the most part, the reach comprises the Otsego City Impoundment in Otsego Township. The impoundment contains large amounts of silt, and the adjacent shoreline is characterized by swampy, marshy conditions (NUS, 1986). The Otsego City Dam impounds water at an elevation of 699 feet above MSL (United States Geological Survey [USGS], 1973). [redacted] and impounds approximately 500 acre-feet of water.

Otsego City Dam to Otsego Dam. From the Otsego City Dam approximately 3.4 miles downstream to the Otsego Dam, the Kalamazoo River has an average width of approximately 200 feet and an average depth of approximately 3.8 feet (BBL, 1994e). While in use, the [redacted]l, had a head of 14.5 feet and impounded water with a surface area of approximately 330 acres (Miller, 1966). The remaining sill of the Otsego Dam has a head of approximatel[redacted](Johnson et al., 1989) and has an impounded surface area of about 83 acres (Appendix B). The contributing drainage area to the dam is approximately 1,474 square miles (Hayes, 1996a). Pine Creek discharges to the river near the middle of the former Otsego Impoundment. The impoundment has been drawn down, which exposed historically-deposited sediments that have since revegetated. According to the MDNR, stages higher than 676.4 feet above MSL will result in flowing water passing over the cut-back portions of the embankment adjacent to the spillway and the former powerhouse. Spillway capacity at 676.4 feet above MSL is about 3,840 cfs, which approximates the 10-year flood stage (Hayes, 1996a).

Otsego Dam to Trowbridge Dam. The former Trowbridge Impoundment covers approximately the next 4.7 miles of the Kalamazoo River, and has an average width of approximately 248 feet and an average depth of approximately 5.0 feet (BBL, 1994e). The river is fairly well channelized with several islands or marshy areas. Prior to being dismantled to its sill level, the Trowbridge Dam had a head of 21.5 feet and impounded water covering about 546 acres (Miller, 1966). Currently, the sill of the dam has a head of [redacted]and impounds an area of about [redacted](the reach as a whole covers approximately 141 acres), and Schnable Brook enters the river approximately 1.5 miles upstream of the dam. The contributing drainage area to the dam is approximately 1,522 square miles (Hayes, 1996c). The impoundment has been drawn down, which exposed historically-deposited

Morrow Lake. Morrow Lake is impounded by Morrow Dam, and is approximately 3.3 miles long. The lake covers approximately 1,000 acres, has an average depth of 6.0 feet, and an average width of 2,500 feet. The bottom of the lake is predominantly silt. The towns of Galesburg and Comstock are nearby.

Morrow Dam to Portage Creek. Between Morrow Dam and Portage Creek, the Kalamazoo River is approximately 4.8 miles long, with an average channel width of approximately 196 feet and average water depth of approximately 3.0 feet (BBL, 1994e) The river bottom is predominantly gravel, sand, and detritus (MDNR, 1982). The river in this segment covers approximately 112 acres and flows through Comstock Township, which includes the Village of Comstock and Kalamazoo Township. Davis Creek flows into the Kalamazoo River east of the WB/A-OU, and Comstock Brook enters the river near the Village of Comstock.

Portage Creek. Portage Creek from Alcott Street to its confluence with the Kalamazoo River is approximately 2 miles long, with an average width of approximately 32 feet and an average depth of approximately 2.3 feet (BBL, 1994e). It covers approximately 8 acres. Portage Creek is a free-flowing stream; however, significant portions are channelized to reduce flooding potential.

Portage Creek to Main Street, Plainwell. The Kalamazoo River between Portage Creek and Main Street in Plainwell is approximately 15.2 miles long and covers approximately 331 acres [redacted] with an average width of approximately 174 feet and an average depth of approximately 3.5 feet (BBL, 1994e). It is considered a net erosional zone with a predominantly sand and gravel bottom (Towns, 1984). Tributaries to the river in this segment are Silver Creek in Cooper Township (south of the Allegan County line) and Spring Brook in Kalamazoo Township (just south of the City of Parchment). The river in this reach flows through the City of Kalamazoo, Cooper Township, Gun Plain Township, and the Town of Plainwell.

Main Street, Plainwell to Plainwell Dam. From Main Street, Plainwell, approximately 1.9 miles downstream to the Plainwell Dam, the Kalamazoo River has an average width of approximately 197 feet and an average depth of approximately 3.7 feet (BBL, 1994e). [redacted] (Miller, 1966). [redacted] (Johnson et al., 1989)[redacted] ([redacted]B). The contributing drainage area to the dam is approximately 1,299 square miles (Hayes, 1996b). A portion of the former impounded area now lies exposed above the existing water line. This exposed area is covered with historically-deposited sediments and has since revegetated. This reach is located in Gun sediments that have since revegetated. The former impoundment is located in Otsego and Trowbridge townships. According to the MDNR, stages higher than 660.5 feet above MSL will result in flowing water passing over portions of the embankment adjacent to the spillway and the former powerhouse. Spillway capacity at 660.5 feet above MSL is about 3,900 cfs, which approximates the 10-year flood stage (Hayes, 1996c).

Trowbridge Dam to Allegan City Line. Between Trowbridge Dam and the Allegan City line, the Kalamazoo River is approximately 7.2 miles long, with an average width of approximately 96 feet and an average depth of approximately 4.4 feet (BBL, 1994e). This reach covers approximately 190 acres (Appendix B) and has been characterized as [redacted] (NUS, 1986).

Allegan City Line to Allegan City Dam. The Allegan City Impoundment extends approximately 1.9 miles down the Kalamazoo River from the Allegan City line to the Allegan City Dam. The impoundment has an average width of approximately 655 feet and an average depth of approximately 3.8 feet (BBL, 1994e), and covers approximately 127 acres (Appendix B). Tannery Creek enters the river just upstream of the Allegan City Dam, which has a head of about 9 feet. This river segment is located in Trowbridge and Allegan townships.

Allegan City Dam to Lake Allegan Dam. Lake Allegan is impounded by Lake Allegan Dam and extends upstream [redacted] to the Allegan City Dam. The lake is, on average, approximately [redacted] and approximately [redacted] (BBL, 1994e). [redacted], and the lake stores approximately 14,200 acre-feet of water (Johnson et al., 1989), with a surface area of about 1,650 acres (Appendix B). The average elevation of Lake Allegan is 615 feet above MSL (USGS, 1981a; 1981b). Rossman Creek enters the river just downstream of the Allegan City Dam. This segment is located in Allegan and Valley townships.

Lake Allegan Dam to Lake Michigan. The Kalamazoo River downstream of Lake Allegan, the lower river, is being investigated separately from the upstream reaches and will be characterized in a subsequent RI/FS report. [redacted]ng, with an average width of approximately 442 feet and an [redacted]t (BBL, 1994e). [redacted] The channel bottom consists mainly o[redacted] The banks along the river are relatively low (2 to 6 feet in height) and there are extensive floodplains along the main channel, especially in the middle section of the segment (MDNR, 1987). This segment is located in Valley, Heath, Manlius, and Saugatuck townships.

[redacted] Within the game area the river travels though Koopman Marsh, Swan Creek Marsh, and Ottawa Marsh, as well as Palmer Bayou and Big Dailey Bayou. Koopman Marsh is just downstream of Lake Allegan Dam, followed by Swan Creek Marsh and then the Palmer Bayou. The Big Dailey Bayou is located within the Ottawa Marsh, a 1,700-acre subunit of the game area that serves as a resting area for migratory geese and ducks (MDNR, 1997). The Swan Creek Marsh is classified as a wildlife refuge by the MDNR (MDNR, 1998). As the river leaves the Allegan State Game Area, it is joined by the Rabbit River near the town of New Richmond. The river then flows into the Pottawatomie Marsh and Morrison Bayou, followed by the Village of Douglas. As the river approaches the Village of Douglas, it widens into the Douglas Bayou and then forms Kalamazoo Lake in the City of Saugatuck. The last quarter mile of the river is an engineered navigation channel outlet to Lake Michigan.

Seems we need to decide what to do w/ dams before cleanup can start. If dams go away, there will be a lot more floodplain soils exposed. When will state decide the fate of the dams?

Section 2
Site Investigation

Section 2

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

Over the past eight years, extensive investigations have been conducted to assess the nature and extent of PCB and other contaminants at the Site.

Collecting sediment cores from the Kalamazoo River

More than 5,000 samples analyzed for PCB have been collected from:

- Surface water
- Sediment
- Floodplains
- Biota – fish, turtles, mice, earthworms & plants

Other work

- To make sure the focus on PCB was correct, many samples were analyzed for several other chemicals.
- A number of studies of the movement and effects of PCB, including continuing studies which are not part of the official RI, are presented in the accompanying *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

Has the whole river been studied?

Although the federal Superfund Site consists of the 35 miles of river between Kalamazoo and Allegan (and the first 3 miles of Portage Creek), the area studied includes the river from Morrow Lake to Lake Michigan. This RI report focuses on the upper river only. A separate RI report will discuss the lower river between Lake Allegan Dam and Lake Michigan.

How do I find out more about the RI/FS?

The investigations discussed here are just part of the overall effort to address PCB in the Kalamazoo River. Dozens of other reports and documents are available for reference at your local public library or by contacting the MDEQ.

See Section 4 for more on Nature and Extent.

2. Site Investigations

The following section presents a description of RI activities completed as prescribed in the RI/FS Work Plan (BBEPC, 1993f) and subsequent RI/FS Work Plan Addendum 1 (Brown, 1995a), Addendum 2 (Brown, 1995b), and Addendum 3 (BBL, 1997), as well as the *Supplemental Kalamazoo River Sediment and Floodplain Soils Work Plan* (BBL, 2000d). Extensive investigations have been conducted to assess the nature and extent of regulated constituents at the Site. These investigations have produced a large volume of data that are presented in reports and technical memoranda submitted to the MDNR and MDEQ (see Section 1.1 and References). [redacted]. A summary of the PCB sampling performed to date as part of the Kalamazoo River RI is provided in the table on the next page. The scope and methods of the various Site investigations are summarized in this section. For more detailed information concerning the Site investigation methods, quality assurance/quality control (QA/QC) information, field notes, and laboratory analytical results, please refer to the reports and technical memoranda.

> **Section Summary**
>
> Between 1993 and 2000, extensive investigations assessed the nature and extent of contamination at the Site. Highlights include:
>
> - Research into possible past and present sources of PCB.
> - Investigation of surface water during normal flow and storm events.
> - Investigation to assess whether PCB or other contaminants migrated into Kalamazoo River and Portage Creek floodplain soils in significant concentrations.
> - Sampling and analysis of Kalamazoo River and Portage Creek [redacted]:
>   - more than [redacted] for PCB and other sediment characteristics.
>   - evaluation of when and where PCB were deposited.
>   - analysis of PCB distribution in the exposed sediments of the three MDNR-owned former impoundments.
> - Sampling and analysis of nearly [redacted] from 11 sampling areas and [redacted] samples from five sampling areas.

Other studies of the movement (i.e., transport and fate), and effects of PCB in the Kalamazoo River are described in the accompanying *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). In 1999, the KRSG assembled a team of experts to assess the need for additional data to supplement certain sections of the RI/FS. This team, which included representatives from BBL, Environ, Arcadis JSA (JSA), Limno-Tech, Inc. (LTI), and Michigan State University (MSU), recommended a series of studies to supplement the RI/FS. Despite these recommendations, the MDEQ indicated it believed these studies were unnecessary. Given their potential significance to the RI/FS, however, the KRSG elected to perform the additional studies, which are ongoing and presently under review by the MDEQ. The data received to date are presented in the accompanying *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). Some of these data support conclusions drawn that cannot reliably be drawn based solely on previous data,

Explain why this work wasn't done under AOC — cuz State didn't want it done?

and provide much more confidence in the evaluation of remedial alternatives. The additional sampling and analyses have been, and continue to be, [redacted].

Need specific here.

Summary of Major PCB Investigations in the Kalamazoo River and Floodplain

Year	Investigation	Description	Samples Analyzed for PCB
1993/94	Source Investigation	Collected 27 cores	95
1993/94	Surface Water Investigation	Event and base flow sampling	172
1993/94	Sediment Probing	Probed sediment, collected 1,068 cores	0
1993/94	Geostatistical Pilot Study	Collected 58 cores	82
1993/94	Geochronological Dating Investigation	Analyzed 4 fine sediment cores	84
1995	Supplemental Geochronological Dating Investigation	Analyzed 4 fine sediment cores	108
1993	Floodplain Investigation	Collected 69 floodplain cores and 6 marsh soil cores	218
1993	Former Impoundment Sediment Investigation	Sampled 21 transects at 159 locations	590
1993	Terrestrial Biota Investigation	Analyzed 15 composite worm, 50 mice, and 43 soil samples	108
1993	Aquatic Biota Investigation	Sampled 363 fish and 33 turtles	396
1997	Fish Sampling	Collected fillet, whole-body, and composite fish samples	136
1997	Analysis of Frozen Sediment Cores	Analyzed 407 cores collected in 1993/1994	1401
1999/2000	Analysis of Frozen Sediment Cores	Analyzed 279 cores collected in 1993/1994	1187
2000	Focused Sediment Sampling	Collected 115 cores from depositional areas	483
	Total Samples Collected		5,060

Is this the supplemental investigation?

Notes:
- Results inclusive of Portage Creek.
- Includes duplicate samples.

2.1 Source Investigation

To satisfy the RI goal of identifying sources of PCB to the Site, preliminary research was conducted (when?) regarding industries or facilities that are or were located in the Kalamazoo watershed and may have discharged, purchased, or used PCB during their operations. A variety of sources were investigated, including, but not limited to, the following:

- Monsanto's PCB sales records;
- Michigan Act 60 (PCB-related regulation) information;
- Dun & Bradstreet records;
- Historical records, trade journals, newspaper articles, and telephone directories within the watershed;
- FINDS (Facilities Index Data System) database for Kalamazoo and Allegan counties;
- Toxic Release Inventory (TRI) data for 1989;
- National Pollutant Discharge Elimination System (NPDES) Permit Compliance System;
- Michigan's Act 307 list; and
- Records from the MDNR and United States Environmental Protection Agency (USEPA) files obtained through Freedom of Information Act (FOIA) requests.

The Monsanto PCB sales records and Act 60 information provided a starting place to investigate contributors of PCB to the Kalamazoo River watershed. From there, microfilms of historical issues of the *Kalamazoo Gazette* were researched for information about the companies identified from Monsanto and Act 60 records. Next, select Michigan Manufacturer's indexes and Kalamazoo phone books from 1945 to 1976 were checked for paper and box manufacturers, electrical generators, hydraulic equipment manufacturers, foundries, scrap-metal dealers, waste paper dealers, and ink manufacturers. A search of the Dun & Bradstreet database was conducted for local companies with certain Standard Industrial Classification (SIC) codes. This information, along with materials found in the original MDNR files provided to the KRSG in 1990, provided the foundation for the master candidate list.

With the master candidate list assembled, field research was conducted in Michigan. BBL personnel visited the libraries and historical associations for communities within the watershed. Historical news clippings files, town records, trade journals, and microfilms of the *Kalamazoo Gazette* were reviewed to gather information about the sites on the master candidate list and to discover new sites. Specific additional research included:

- A FOIA request was made to the MDNR to obtain NPDES records of facilities in the Kalamazoo River watershed. Likewise, the NPDES Permit Compliance System was consulted for additional discharge information.

- A FINDS database search was performed to obtain additional site names. FINDS contains companies which have reported information to the USEPA.

- The TRI, which provides information of USEPA-regulated chemicals which have been released by companies, was reviewed to determine the amount of chemical released and the receiving media.

- The Michigan Act 307 list, currently known as the *Contaminated Sites in Michigan Database*, for fiscal year 1993 was reviewed to locate other contaminated sites which have been identified by the State.

Additionally, many MDNR and USEPA representatives were contacted for information about the watershed. The information obtained included sewer system maps, Notification of PCB Activities form details, and solid waste management plans.

As a result of this research,[redacted] Sediment cores were obtained at targeted locations. The top 6 inches of sediment from each core was analyzed for PCB and total organic carbon (TOC). Below the 0- to 6-inch interval, the sediment core was sectioned into samples representing a 6- to 12-inch interval and subsequent 1-foot increments thereafter to the total depth of the sediment core. Approximately 95 samples were analyzed.

2.2 Mill Investigations

> - Goal – find out whether or not the six mill properties were potential or ongoing sources of PCB.
> - 63 samples analyzed for PCB.
> - See Section 4.7.1 for results and summaries of cleanup activities within these areas.

Six properties located on the Kalamazoo River and Portage Creek within the Site were investigated to assess: 1) the presence of PCB in areas where residuals had been stored for disposal; and 2) the potential for PCB to be released to the river. The investigations are discussed in detail in the *Technical Memorandum 15* (BBL, 1996a). The six properties studied were:

- Former Allied Paper, Inc. Bryant Mill (Figure 2-1);
- Former Allied Paper Company King Mill (Figure 2-2);
- Georgia-Pacific Corporation Kalamazoo Mill (Figure 1-15);
- Simpson Plainwell Paper Company Mill (currently known as the Plainwell, Inc. Mill) (Figure 2-3);
- The King Street storm sewer area (KSSS) (Figure 1-15); and
- Former Allied Paper Company Monarch Mill (Figure 2-4).

[redacted]. The sampling activities at the mill properties focused on mill residuals and solid residue that could come in contact with surface runoff, other water discharged to the river or creek, or the river and creek themselves. In addition to PCB, certain locations were also screened for polychlorinated dibenzodioxins and dibenzofurans (PCDD/PCDF).

Secondary objectives of the Mill Investigations were to:

- Assess the presence and distribution of PCB in former on-site lagoons;
- Assess the presence of PCB in former and present wastewater treatment structures and piping; and
- Assess the presence of PCDD/PCDF in former and present stormwater conveyance piping.

During initial RI sampling, a total of 37 borings/cores were installed at the four mills and the KSSS area. From these borings/cores, 13 residuals, 5 residuals/soil, and 34 soil samples were analyzed for PCB. Two grab samples requested by the MDNR, six wastewater-related samples, and three stormwater-related samples were also analyzed for PCB. The three stormwater-related samples were analyzed for PCDD/PCDF, and one soil sample was analyzed for USEPA Contract Laboratory Program (CLP) Target Compound List/Target Analyte List (TCL/TAL) constituents.

2.3 Floodplain Soils Investigations

> - Goal – find out if contaminated sediments had been transported to the floodplains.
> - 218 samples analyzed for PCB.
> - See Section 4.1 for results.

[redacted]s. The investigation of floodplain soils is discussed in *Technical Memorandum 3* (BBL, 1994c) and *Addendum 1 to Technical Memorandum 3* (BBL, 1996b).

The initial investigation strategy focused on the sampling of flood-prone areas that would have been most likely to accumulate sediments exported from the river channel. Field work was conducted during July and August 1993. Eight Kalamazoo River floodplain sampling transects and two Portage Creek transects were established in flood-prone areas, extending to the approximate limit of the 100-year floodplain. These sampling efforts yielded 72 cores and 208 samples for PCB analysis.

Three additional cores (10 samples) were subsequently collected from a selected section of the Portage Creek floodplain where elevated PCB concentrations were observed during the first investigation. Surficial samples from each location in this supplemental effort at Portage Creek were also analyzed for TOC.
In addition, one floodplain location near the river was selected at random by field personnel, in concurrence with MDEQ representatives, for USEPA CLP TCL/TAL analyses.

2.4 Sediment Investigation

To assess the nature and extent of PCB in the Kalamazoo River and Portage Creek sediment, a Sediment Investigation was performed in accordance with the RI/FS Work Plan (BBEPC, 1993f) and Addendum 2 (Brown, 1995b) and Addendum 3 of the RI/FS Work Plan (BBL, 1997). This investigation included the following components:

> - Goal – gather information to evaluate the nature and extent as well as the movement of PCB in the river and creek. See Sections 4 and 5 for a more detailed discussion.
> - Sediment cores gathered in 1993 and 1994 from 1,068 locations.
> - Cores were frozen and more than 2,500 samples were analyzed for PCB in 1997, 1999, and 2000.
> - Supplemental sediment studies:
>   - Geostatistical pilot study (82 samples)
>   - Geochronologic analysis (192 samples)
>   - Focused sampling (483 samples)
> - See Section 4.3 for results.

- [redacted] in the Kalamazoo River between Morrow Dam and M-89 downstream of Lake Allegan Dam, and along [redacted] between Alcott Street and the Kalamazoo River. At each location, water and sediment depth were measured, and, [redacted] future analyses (197 cores were too coarse to be recovered). Channel width was measured at each transect, and all probing locations were surveyed. In addition, velocity measurements were taken at 44 transects, along with grain-size characterization and sediment descriptions (e.g., sediment composition, color, presence of debris, and types of coarse material). Results of the Sediment Characterization were reported in *Draft Technical Memorandum 10* (BBL, 1994e).

- At the time of sediment characterization work, 58 sediment cores were collected to support a geostatistical pilot study. Seventy-four samples were analyzed for PCB (82 including duplicate samples).

- Eight sediment cores were collected, four in 1993 and four in 1995, finely-sectioned, and analyzed for the radioisotopes Cesium^{137} (^{137}Cs) and Beryllium^{7} (^{7}Be) for geochronologic analysis. Based on the results, a total of 192 samples from these investigations were analyzed for PCB.

- In 1997, 407 sediment cores collected in 1993/94 and retained in frozen storage were sectioned and analyzed. This effort included 1,261 samples for PCB analysis (1,401 including duplicate samples), 841 samples for TOC analysis (936 including duplicates), and 416 samples for particle-size analysis. In addition, 33 samples from the fine-grain cores obtained from each reach were analyzed for TCL/TAL constituents. The results are presented in Appendix C.

- In 1999-2000, 279 additional frozen sediment cores collected in 1993 and 1994 were sectioned and analyzed at the MDEQ's request. This investigation resulted in 1,069 additional analytical samples (1,187 including duplicates) for PCB, TOC, and particle size analyses.

- In April through July 2000, sediment and floodplain cores were collected at locations identified by the MDEQ for "focused sampling." Cores were collected at 115 locations, sectioned, and analyzed, resulting in 483 samples (including 52 duplicates) for PCB, TOC, and particle-size analyses. ? what's "focused Sampling?"

Each component of the sediment investigation provides specific information pertaining to the evaluation of the nature and extent, fate, and transport of PCB in the Kalamazoo River. The data generated from the sediment investigation were used to characterize the nature and extent of PCB in sediment, assess the factors that affect the nature and extent of PCB in the sediment, evaluate the spatial variability of PCB in the sediment, estimate historical and current sediment deposition rates, and evaluate areas specifically targeted for sampling by the MDEQ.

An important aspect of the methods of PCB analysis used for this RI is the reporting of detailed chromatographic information about the composition of PCB in samples from the Site. The 1993 Work Plan anticipated the need to assess the composition of PCB in samples in order to properly analyze the transport and fate of PCB in the Kalamazoo River. That assessment is needed to more fully understand the sources of PCB to and within the river, the biodegradation of PCB as it may be occurring in sediment, and the differential transport and bioaccumulation of PCB compounds. To support these assessments, electronic versions of the analytical traces (known as chromatograms) were reported for each sample. These chromatographic data files allow the PCB composition to be broken down into generally 80 to 120 components ranging from low molecular weight PCB (e.g., dichlorobiphenyl) to high molecular weight PCB (e.g., octachlorobiphenyls).

2.4.1 Sediment Characterization

> - Sediment samples were analyzed for:
>   - PCB
>   - Particle size distribution
>   - TOC
>   - Percent solids
> - See Section 4.3.1 for results.

[redacted], which included the collection of extensive physical and analytical data throughout the river and Portage Creek, [redacted]. The 1993 sediment probing data, presented in *Draft Technical Memorandum 10* (BBL, 1994e), provided data used to evaluate the occurrence and distribution of sediment within the Site and to calculate sediment volumes within various reaches. In addition, the subsequent analysis of 686 cores (in 1997 and 2000) for PCB, TOC, and particle-size distribution allows for the characterization of the nature and extent of PCB horizontally and vertically within the sediment bed. Including the 1997 and 2000 analyses of frozen cores, 2,588 samples were analyzed for PCB, 2,122 samples were analyzed for TOC, and 864 samples were analyzed for particle-size distribution. These data can be used to develop correlations of PCB concentration with sediment characteristics, which ultimately determine the fate and transport of PCB. In addition, physical data (such as percent solids, which was measured and reported as part of the PCB analyses) were used to estimate the mass of PCB within the sediment.

Other studies of Kalamazoo River sediment are described in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). Additional sediment cores were collected by the KRSG in 2000 for PCB, TOC, and particle size distribution analyses. The objectives of that sampling are to:

- Provide an up-to-date assessment of PCB distribution in the Kalamazoo River sediment that can be used to assess potential changes over time by comparison with PCB data from the cores collected in 1993 and 1994;
- Confirm the distribution of fine and coarse sediments observed in the 1993/1994 sediment cores, and refine estimates of sediment volumes and PCB mass distribution in the river;
- Provide data that are comparable to, and correspond in time with, PCB data being collected at the MDEQ's request from the sediment and marshes in the Kalamazoo River downstream of Lake Allegan;
- Characterize the sediment and PCB distribution in Morrow Lake;

- Provide PCB and other data that can support development of mathematical models of sediment and PCB transport, as contemplated by the 1993 MDNR-approved Work Plan; and

- Characterize sediment PCB concentrations that correspond to the results of the most recent fish and surface water sampling performed by the KRSG.

Sampling activities considered part of the sediment characterization include the collection of 400 cores between Morrow Dam and Lake Allegan Dam for PCB and other analyses, 16 cores in Morrow Lake for PCB and other analyses, 50 cores from between Morrow Dam and Lake Allegan Dam for analysis of geotechnical properties, and the measurement of potential sediment resuspension rates. Description of these sampling efforts are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). [redacted]

2.4.2 Geostatistical Pilot Study

> ➢ Goal – analyze variations in PCB levels over distance.

The geostatistical pilot study was designed and conducted early in the RI to help determine the sampling methods that would be used to assess the distribution of PCB in the river sediments. [redacted] Simply put, the more variable PCB concentrations found over short distances, the more samples would be necessary to support the use of kriging. In the end, use of the kriging method might not be justified if the sampling requirements were so great that alternative methods such as stratified sampling would be more cost effective. [redacted]. The more intensive sampling supported a geostatistical data analysis to quantify the variability in both the lateral and longitudinal directions. The results of this pilot study are presented in *Draft Technical Memorandum 10* (BBL, 1994e).

2.4.3 Geochronologic Investigation

> ➢ Goal – estimate PCB deposition rates over time.

The rate of change in PCB transport and deposition in the Kalamazoo River over time is particularly important when assessing PCB in the

Kalamazoo River. Historical rates of sediment deposition and transport of PCB were approximated through analysis for the radioactive isotope ^{137}Cs in finely-sectioned sediment cores from the Allegan City Impoundment and Kalamazoo Lake. ^{137}Cs findings were used to characterize the sediment strata within the core. Based on known historical radioactive fallout patterns (distinctive due to nuclear weapons testing during the 1950s and 1960s), the approximate depth of sediment in which ^{137}Cs first appears marks the 1954 horizon, and peak ^{137}Cs activity marks the 1963 sediment layer (Pennington, et al., 1973). Combined with analysis of PCB in strata of the same core, a chronology of PCB transport and deposition can be approximated. Geochronologic cores were collected from areas favoring sediment accumulation with minimal disturbance (i.e., back waters). Geochronological cores collected as part of the RI include four cores each from Allegan City Impoundment and Kalamazoo Lake which were analyzed for radionuclides and PCB in 1993 and 1995. More detail on this investigation is contained in *Draft Technical Memorandum 12* (BBL, 1994d) and the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

Eighteen additional sediment cores were collected for isotope and PCB analysis in 2000. These cores included two from each of the former and existing impoundments from Morrow Lake to Kalamazoo Lake, with the exception of Lake Allegan, from which four cores were collected. These cores will assist the spatial evaluation of current and historical sediment and PCB deposition rates.

2.4.4 MDNR-Owned Former Impoundment Sediment Investigation

- Goal – characterize the distribution of PCB in the exposed sediment of the former impoundments.
- 590 samples analyzed for PCB.
- Wetland assessment conducted (see Appendix D)
- See Section 4.2 for results.

The primary objective for the investigation of the exposed sediments in the former impoundments was to assess the distribution of PCB-containing sediment and other constituents of concern or regulated components within the boundaries of the former Plainwell, Otsego, and Trowbridge impoundments. The investigation of the exposed sediments is discussed in detail in *Draft Technical Memorandum 12* (BBL, 1994d), and is summarized below.

Sediment samples were collected along transects that were extended outward from the river's edge until: 1) field screening kits indicated PCB concentrations were below a detection limit of 1.0 milligrams per kilogram (mg/kg); 2) a gray sediment/native soil interface could not be identified; or 3) field personnel encountered a physical feature that, based on elevation, would clearly be outside of the former impoundment (e.g., a steep bank). Six transects were established within each of the former Plainwell and Otsego impoundments, and nine transects were established within the former Trowbridge Impoundment. Sediment cores collected from November 1993 to February 1994 produced a total of 590 samples for PCB analysis. The 0- to 6-inch depth interval for all cores, and the deeper intervals for half of the cores, were analyzed for TOC content. One core per impoundment was screened for TCL/TAL constituents. Every sample was physically characterized using the Unified Soil Classification System (USCS), as specified in the RI/FS Work Plan (BBEPC, 1993f).

A wetland assessment was also performed for the former Plainwell, Otsego, and Trowbridge impoundments, and consisted of the following components:

- Identification of wetlands within the limits of the former Plainwell, Otsego, and Trowbridge impoundments;
- Identification of the physical and biological characteristics of the identified wetlands;
- Evaluation of the functions and values of the identified wetlands using the U.S. Army Corps of Engineers (USACE) Wetland Evaluation Technique (WET) (USACE, 1987); and
- Evaluation of the habitat quality of the identified wetlands for target wildlife species.

More detail regarding the wetland assessment is presented in Appendix D.

[redacted]). Rough estimates of annual PCB loading from the banks of the former impoundments indicated that PCB losses from the banks could be of the same magnitude as annual transport of PCB in the Kalamazoo River. This highlighted the importance of making direct measurements of bank erosion. Subsequent work included the resurvey of banks in 1999 at transects previously surveyed during the 1993 and 1994 investigations, and the establishment of erosion pins to quantitatively provide periodic erosion estimates in relation to monitored flow conditions. Data generated from the 1999 resurvey of former impoundment riverbanks provide estimates of PCB loading to the river from the banks, complement empirical estimates provided in this report, and affect the conclusions of the remedial alternatives evaluation.

Measurement of erosion from river banks

2.4.5 Focused Sampling

In addition to the sediment investigations described above, a focused sampling effort began in May 2000 to target the depositional areas between Morrow Dam and Lake Allegan Dam. The MDEQ selected sampling locations that were identified as floodplain depositional zones; recently active oxbows; islands; accidental, permitted, and un-permitted waste disposal areas; or areas of potential sediment deposition. Cores were collected at 115 locations, resulting in 483 samples (including 52 duplicates) for PCB, TOC, and particle size analyses. Results are presented in Appendix E and discussed in Section 4.4 of this report.

2.5 Surface Water Investigation

The primary objectives of the Surface Water Investigation were to assess ambient PCB levels and to characterize the rates and mechanisms of PCB transport in the Kalamazoo River and Portage Creek. The Surface Water Investigation is discussed in detail in *Draft Technical Memorandum 16* (BBL, 1995a) and is summarized below.

> - Goal – characterize rates and mechanisms of PCB transport.
> - 172 samples collected during both baseflow and highflow conditions.
> - See Section 4.5 for results.

PCB transport and concentrations in the water column were characterized during high-flow runoff events and during baseflow conditions. These characterizations were used in conjunction with continuous flow data to estimate the annual PCB mass load in the Kalamazoo River. Water quality data, such as total suspended solids (TSS) and water temperature, were used to help further characterize PCB transport by allowing the estimation of the influence and extent of processes such as sediment scour, resuspension, and chemical desorption.

Surface water sampling and analyses were conducted at six locations along the Kalamazoo River and one location on Portage Creek from January to September 1994 (Figure 2-5):

- Kalamazoo River at River Street in Comstock (SWK-1);
- Kalamazoo River at Michigan Avenue in Kalamazoo (SWK-2);
- Portage Creek at Gibson Street in Kalamazoo (SWP-3A);
- Kalamazoo River at D Avenue in Cooper Township (SWK-3);
- Kalamazoo River at Farmer Street downstream of Otsego City Dam (SWK-4);
- Kalamazoo River at M-222 downstream of Allegan City Dam (SWK-5); and
- Kalamazoo River at M-89 downstream of Lake Allegan (SWK-6).

A total of 172 surface water samples were analyzed for PCB and TSS. Field parameters also were measured at each location, including water temperature, DO, specific conductivity, pH, turbidity, and air temperature.

In addition to the Surface Water Investigation performed on behalf of the KRSG to support the RI/FS for the Site, other available surface water data include:

- Water quality monitoring data collected by the MDNR at several locations in the mid-to-late 1980s, summarized in the DCS (BBEPC, 1992);

- Particulate and dissolved PCB congener data collected by the USEPA as part of the Lake Michigan Mass Balance Study (LMMBS) (USEPA, 1993); and

- Long-term monitoring data collected in 2000 on behalf of the MDEQ, conducted in accordance with the *Final Long Term Monitoring Plan* (CDM, 1999e).

Initial results of surface water [redacted] are presented in the *Supplement to* [redacted] (BBL, 2000e). A significant year-long comprehensive surface water sampling program was initiated by the KRSG in March 2000. This sampling is being performed on behalf of the KRSG by LTI with assistance from Western Michigan University (WMU). Objectives of the present sampling activities are to update and improve PCB load estimates and transport characteristics, develop a river-wide sediment mass balance, and support the development of a sediment and PCB transport model. The surface water sampling program is similar to the 1994 RI in that it targets both base flow and high flow events. However, the surface water sampling program will provide a more comprehensive characterization through the collection of routine, bi-weekly samples for PCB analysis, tributary sampling to provide solids loading estimates, TOC analysis, periodic collection of samples for dissolved and solids-phase PCB analysis, and two synoptic surveys of PCB in the river at additional locations to spatially characterize PCB in the water as it moves downstream.

2.6 Biota Investigations

> - Goal – sample and analyze various terrestrial and aquatic biota to develop a clearer picture of potential human and ecological exposure to PCB.
> - Total of 640 samples from fish, mice, and worms analyzed for PCB.
> - See Section 4.6 for results.

The Biota Investigations were designed to produce data to assess potential human and ecological exposure to PCB, certain pesticides, and mercury, as well as to assess temporal trends and spatial gradients in fish PCB concentrations. [redacted], were performed in accordance with the *Biota Sampling Plan* (BSP) for the Site, prepared by CDM on behalf of the MDEQ (CDM, 1993). Species sampled were selected based on their function within the Kalamazoo River ecosystem and their potential role in human and ecological exposure pathways. Data for selected aquatic biota ([redacted]) were used to estimate the exposure of humans who may consume them. Data for selected terrestrial biota (mice and earthworms) that are consumed by higher-trophic-level organisms were used to estimate exposure of those organisms. The Aquatic Biota Investigation and Terrestrial Biota Investigation are discussed in *Draft Technical Memorandum 14* (BBL, 1994f) and its three draft addenda (BBL, 1994g; 1995c; 1998). Results of 1997 fish monitoring were reported to the MDEQ in *Draft Addendum 3 to Technical Memorandum 14* (BBL, 1998).

Additional studies and results of PCB levels in biota are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). [redacted] to evaluate current levels of PCB[redacted]s, [redacted]es, [redacted]els, and to [redacted]ts. Data collection included [redacted]ion. Sample collection and analysis was performed in accordance with the same protocols and procedures used during the MDEQ-approved 1993 and 1997 sampling efforts.

Researchers from [redacted] also initiated a comprehensive ecological sampling program in 1999. [redacted] than is possible based on previously existing data. Data collection includes PCB congener analysis of biota samples in conjunction with similar congener analysis of sediment and soil, plant samples for PCB analysis, eagle egg sampling and PCB analysis (with assistance from the U.S. Fish and Wildlife Service [USFWS]), song bird nesting and reproduction data, and a study of home ranges and foraging behavior for raptors. The study began in 2000. A description of the study, the results received to date, and the preliminary ecological risk assessment using those results are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

2.6.1 Aquatic Biota Investigation

> ➢ The Aquatic Biota Investigation included fish and turtle sampling and analysis.

[redacted]d from aquatic biota sampling areas (ABSAs) 1 through 11, covering the area of river between Battle Creek and New Richmond (Figure 2-5). Fish species collected included [redacted] Eleven of each species were collected from each location. Each fish was weighed, measured, photographed, and examined for external abnormalities. The fish were then processed as either whole-body or fillets (as specified in the BSP [CDM, 1993]) and shipped to the laboratory. [redacted]. In addition, [redacted] (i.e., those with relatively high reported PCB concentrations) [redacted]. The results of the 1993 Aquatic Investigation are presented in *Draft Technical Memorandum 14* (BBL, 1994f).

In [redacted] a total of [redacted] including [redacted] composite samples (consisting of five fish each) were collected to provide additional data for evaluating PCB trends in fish. The fish were collected from several of the ABSAs sampled in 1993 (i.e., ABSAs 1, 2, 5, 9, and 11). [redacted] The selection of yearling smallmouth bass as a target organism and their grouping into composite samples for analysis was intended to provide a low-variance tool for monitoring changes in fish PCB levels over time. Consistent with the analysis of the 1993 samples, each fish was weighed, measured, photographed, examined for external abnormalities, and processed prior to shipment to the laboratory for PCB and lipid analyses. The results of the 1997 fish sampling are presented in *Draft Addendum 3 to Technical Memorandum 14* (BBL, 1998).

[redacted] Fish sampled included [redacted] at each of ten sampling locations. The results of this investigation, along with a comparison to historical data, are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

A total of [redacted] (*Chelydra serpentina*) were sampled from three ABSAs:

- ABSA 1 – Kalamazoo River near I-94 upstream of Battle Creek;
- ABSA 5 – Kalamazoo River between the Highway 131 bridge in Plainwell and Plainwell Dam; and
- ABSA 10 – Kalamazoo River downstream of Allegan Dam.

Eleven turtles were collected from each ABSA from August 27 to October 10, 1993, and May 16 to 31, 1994, using trapping techniques and procedures described in the BSP. Prior to shipment to the laboratory, each turtle was weighed, measured, and examined for external abnormalities. Sample processing in the field included preparation of whole-body samples (minus the shell) and muscle-only (neck and leg muscle) samples according to procedures in the BSP.

2.6.2 Terrestrial Biota Investigation

The Terrestrial Biota Investigation was designed to generate PCB data from selected species for use in the ecological risk assessment component of this RI. [redacted] soil samples were collected in conjunction with selected biota [redacted]s) to estimate possible exposure of identified consumer species that use these species as food sources. The investigation consisted of terrestrial biota sampling in five designated terrestrial biota sampling areas (TBSAs) representative of specific ranges of soil PCB concentrations. Sampling provided PCB data for surface soils and target biota species.

The 11 candidate TBSAs were selected in accordance with the BSP (CDM, 1993). The BSP identified 11 preliminary TBSAs along the Kalamazoo River based on the availability of suitable habitat for small mammals and suspected PCB concentrations in surficial soils. To accomplish the final designation of five TBSAs for biota sampling, an initial soil sampling investigation was conducted (Phase I).

Based on the results of Phase I screening, TBSAs 1, 3, 5, 10, and 11 (Figure 2-5) were selected for further, more intensive sampling during the Phase II Terrestrial Biota Investigation. A total [redacted] were collected (including three duplicate samples) and analyzed for PCB. The results of the Phase II TBSA soil sampling are presented in the *Addendum to Technical Memorandum 2* (BBL, 2000c). [redacted] and [redacted] were collected from each of the Phase II TBSAs and analyzed for PCB and lipid content. The results of these samples are presented in *Draft Technical Memorandum 14* (BBL, 1994f).

[redacted]e [redacted]nt, which is described in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). Additional biota sampling, including plants, was performed at the former Trowbridge Impoundment and near Ceresco to assess ecological exposure to PCB. This comprehensive sampling program was developed and is being performed by researchers at MSU. The sampling program and the more comprehensive ecological risk assessment based on results received to date are described in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). No mention of State's eco RA.

2.6.3 Other Biota Data

The biota investigations described above were performed on behalf of the KRSG specifically to support the RI/FS. [redacted]r, including Morrow Lake. These data, which are incorporated into analyses in this RI report, include:

- Numerous fish fillet samples collected on six occasions between 1985 and 1994 to support the Michigan fish contaminant monitoring program, including fish fillets of several fish species for the assessment of the fish consumption advisories issued by the MDCH; and
- Whole-body carp data from Lake Allegan collected on five occasions between 1990 and 1999.

2.7 Data to Support Remedial Alternatives Development and Analysis

[redacted]r. Examination of such physical characteristics are important to properly estimate the effectiveness, implementability, and cost of various remedial alternatives. The additional studies, which are described further in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e), include:

- [redacted] of key areas of the Kalamazoo River was performed, and accompanying maps of sediment characterization will be generated. This study, carried out by Ocean Survey Inc., entailed the use of sonar and side-scan sonar where possible. The bathymetry and sediment character maps that are being generated will be used to [redacted]n as well as to [redacted] and [redacted]es. In addition, results of this work [redacted] in the river sediment that may affect the implementability, effectiveness, and costs of remediation methods. Results of this study are expected in November 2000.

- A diver survey of Lake Allegan sediment was conducted to specifically characterize bottom conditions in the lake and to identify and map debris within surveyed areas of the lake.

- A [redacted]s in representative areas was performed in 2000 to [redacted]eral remedial alternatives and to better estimate the implementability of, and costs associated with, various remedial alternatives. Riverbank surveys included general observations of accessibility, ability to support staging activities and road-building, and tree counts to assist in the conceptual design and cost development of remedial alternatives.

Results of these studies are potentially very significant to the conclusions of the FS. More complete descriptions of these studies, results received to date, and their implications are provided in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

Section 3

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

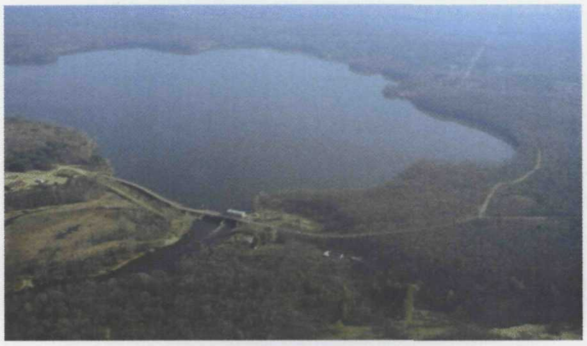
Section 3
Physical Characterization

Inside Section 1 – Introduction
Inside Section 2 – Site Investigations

Inside Section 3 – Physical Characteristics of the Site

Inside Section 4 – Nature and Extent of Contamination in the Kalamazoo River System
Inside Section 5 – PCB Fate and Transport
Inside Section 6 – Risk Assessment
Inside Section 7 – Site Conceptual Model and RROs

Lake Allegan is the largest surface water feature on the Kalamazoo River. It covers 1,600 acres and traps much of the sediment and PCB that enter it from upstream.



Physical characteristics of the Kalamazoo River greatly affect the movement of PCB. The river is a stable system, with little long-term variability in flow. The reaches of the river can be divided into two basic categories:

Impounded Areas

- Slow the flow of the river.
- Act as traps for sediment and PCB.
- Accumulate fine-grained sediment.

Free-Flowing Reaches

- Have higher water velocity.
- Do not serve as depositional areas.
- Are generally erosional in nature.
- Contain coarse sediment.
- Contain relatively little PCB mass.

Other Characteristics of the River

Ecology

Seven native plant communities and a variety of wetlands provide good habitats for many plants and animals. The area hosts two federally-endangered species, two federally-threatened species, and one federal candidate species. The state of Michigan classifies nine species as threatened or endangered and eight as species of special concern.

Former Impoundments

The MDNR-owned former Plainwell, Otsego, and Trowbridge impoundments play a key role in the river system. For example, when the dams were opened by MDNR in the early 1970s, PCB-containing sediment was released downstream and about 500 acres of formerly-submerged sediments were exposed. The banks of these exposed sediments continue to erode today, carrying PCB into the river.

Transport of pollutants, suspended solids, and other particles tends to be relatively consistent in a stable river with little response to floods.

See Section 5 for more on Fate and Transport.

3. Physical Characteristics of the Site

The Kalamazoo River watershed is located in the southwestern portion of Michigan's lower peninsula (Figures 1-1 through 1-13). The watershed contains approximately 400 miles of stream tributaries and encompasses a drainage area of over 2,000 square miles. The mainstem of the Kalamazoo River forms in the City of Albion with the confluence of the north and south branches. The river flows northwesterly for approximately 123 miles before draining into Lake Michigan near the town of Saugatuck.

Section Summary

The physical characteristics of the Kalamazoo River play a large role in the ultimate fate and transport of PCB. From Morrow Lake to Lake Michigan, the river is a series of alternating free-flowing reaches and existing or former impoundments. The free-flowing reaches are steeper, have higher water velocities, and are generally erosional in nature. The impoundments are quiescent and act as sediment traps by slowing down the river flow and facilitating sediment deposition. Impounded areas also tend to accumulate more fine-grained sediment rich in natural organic matter.

The former impoundments at Plainwell, Otsego, and Trowbridge, were historically depositional until the MDNR drew down the dams in the early 1970s. This lowered the water level and forced the Kalamazoo River to carve a channel through the middle of historically deposited sediment. Hydraulic changes as a result of dam removal also led to steep, unstable, banks which continue to erode, and the creation of wetland habitats within the former impounded areas where the former sediment bed today comprises the floodplain soil. The former impoundments are no longer depositional areas.

The presence of numerous dams along the river combined with a largely rural watershed results in a relatively stable river. Flow generally does not fluctuate a great deal over small time periods, and storm flow events are relatively gradual, occurring over a fairly long period of time (i.e., days to weeks). Between the dams are interspersed reaches of river that exhibit multiple channels, sandbars, and extensive meandering; these areas represent a transient sediment bed that fluctuates routinely.

The Kalamazoo River watershed offers a healthy ecological setting that includes a variety of cropland and pastures, wetland habitats, and forests. There is relatively little industrial or urban land use within the basin except for several municipal areas centered around the Kalamazoo River, which was historically used as both a source of water and a receiving water for wastewater discharge. With the exception of the municipal areas and the shores of Lake Allegan, the land surrounding the Kalamazoo River is largely rural and agricultural.

The character of the river has been greatly affected by the presence, and former presence, of its dams. In particular, the Lake Allegan Dam created Lake Allegan, which now holds the majority of the PCB-containing sediment present in the Kalamazoo River. The former dams at Plainwell, Otsego, and Trowbridge created impoundments covering approximately 1,000 acres (Miller, 1966). All three of these dams were permanently opened in the early 1970s, resulting in the exposed sediment that is a part of this investigation.

3.1 Geology

The geologic setting of the Kalamazoo River basin was shaped by glacial activity that occurred approximately 15,000 to 17,000 years ago. During the retreat of the ice lobes, the Saginaw lobe moved northeast and the Michigan lobe northwest, producing large quantities of outwash sand and gravel deposits, which formed the Galesburg-Vicksburg outwash plain. Also, throughout this period, large blocks of ice broke away from the main ice body and were buried by outwash sediments. As the buried ice slowly melted, the overlying sand and gravel collapsed, forming many of the kettle lakes found throughout the area (Rheaume, 1990).

The retreat of the ice lobes halted temporarily in western Kalamazoo and Allegan counties. In this position, the ice lobes deposited sandy to very sandy till and massive to poorly bedded cobbly sand with isolated lenses and pockets of sandy clay. This depositional event formed the Kalamazoo Moraine, which is one of the largest continuous ridges in southern Michigan. The glacial deposits range in thickness from approximately 50 feet to 200 feet and overlie the Coldwater Shale formed during the Mississippian Period of the Paleozoic Era. The shale is greater than 500 feet thick and dips northeast (Rheaume, 1990).

As the ice lobes continued to retreat, a drainage way was opened in front of the Michigan lobe. Meltwaters that had been draining to the south ponded in the center of Kalamazoo County. The direction of flow changed from south to north, resulting in downcutting of the outwash plain and formation of the down-cut glacial drainage channels of the Kalamazoo River valley. Eventually, the lobes retreated out of Kalamazoo and Allegan counties, creating a new drainage pattern and directing meltwater away from the Kalamazoo River valley. As the new drainage pattern evolved, the flow through the Kalamazoo River decreased to its present pattern (Rheaume, 1990).

3.2 Meteorology

The climate in southern Michigan is temperate. In Kalamazoo, the mean daily maximum temperature is 59.7 degrees Fahrenheit (°F) and the mean daily minimum temperature is 39.7°F. The annual mean precipitation is 34.8 inches, including 73.1 inches of snow (National Climatic Data Center [NCDC], 1951-1980b). In Allegan, the mean daily maximum temperature is 58.6°F and the mean daily minimum temperature is 38.0°F. The annual mean precipitation is 35.6 inches, including 78.4 inches of snow (NCDC, 1951-1980a). Additional meteorological data can be found in Section 2.3 of the DCS.

3.3 Hydrogeology

> ➤ The river and shallow aquifer are hydraulically connected, so there is a close relationship between surface water and groundwater flows.

The primary groundwater aquifers in the Kalamazoo River basin are glacial deposits consisting mainly [redacted]els. The most productive aquifers are the [redacted]n or down-cut drainage way deposits. The Coldwater Shale, which underlies the glacial deposits, yields small quantities of largely mineralized water. Except for rare instances, the Coldwater Shale aquifer is not used as a water source.

Technical Memorandum 13 - Water Well Inventory (BBL, 1995b) presents information regarding the location of wells near the Kalamazoo River and Portage Creek. Five hundred and forty wells were identified within a 1/4-mile and 1/2-mile (depending on river segment) boundary of the Kalamazoo River and Portage Creek. Well depths ranged from 6 to 280 feet. The predominant well usage was identified as domestic.

The USGS has monitored the river stage on the Kalamazoo River (Comstock gage) and the groundwater elevation at a well near Morrow Lake. A USGS monitoring well is located 1,000 feet away from the river in the upstream end of Morrow Lake, which has a screened interval of 24 to 28 feet below ground surface (bgs). After 1 year of monitoring from August 1987 to August 1988, [redacted] (Rheaume, 1990). Changes in groundwater elevations reflect short-term and long-term changes in precipitation and local pumpage. [redacted]

3.4 Hydrology

> ➢ Long-term monitoring at Comstock and Fennville shows there is little annual variability in the flow of the river. Highest flows occur in the spring, and lowest flows occur in late summer and early fall.

The hydrology of the Kalamazoo River from Morrow Lake to Lake Michigan exhibits consistent characteristics with relatively little variability. The USGS has collected long-term flow data from two gages within this reach, one currently operating at River Street in Comstock, located 1.2 miles downstream of Morrow Lake, and one at Fennville, about four miles downstream of Lake Allegan Dam, which was discontinued in 1993. A gage was installed in Portage Creek at Lover's Lane in 1964, and data have been collected continuously at the location since. These data, summarized in the table below, show that at all three locations, flow is relatively stable within and among years. As is typical in northern temperate climates, the highest average daily flows occur in the spring as a result of snowmelt, spring precipitation, and higher runoff rates, while the lowest flows occur in late summer and early fall when water losses to soil infiltration and evapotranspiration are greatest. At all three locations, highest average daily flows occur in March and April; low flow occurs in August at Comstock and Fennville and in September at Portage Creek (see Figure 2-5 for gage locations).

	Comstock	Fennville	Portage Creek
USGS Gauge No.	04106000	04108500	04106300
Source	Blumer et al. (1999)	Blumer et al. (1994)	Blumer et al. (1999)
Period of Record	1932-1998[2]	1929-1993[1]	1964-1998
Drainage Area (mi^2)	1010	1600	22.4
Median Flow (cfs)	750	1290	40
10% Exceedance Flow (cfs)	1530	2450	53
90% Exceedance Flow (cfs)	410	708	29
Average Daily Mean Flows (cfs)			
Period of Record	897	1480	41.2
January	923	1567	39.7
February	986	1647	41.9
March	1379	2207	47.1
April	1357	2189	49.0
May	1060	1748	44.6
June	873	1418	41.9
July	676	1070	39.2
August	576	949	27.5
September	584	993	36.9
October	681	1136	37.4
November	800	1358	39.4
December	863	1509	40.0

Notes:

1 Actual period of record included April 1929 - September 1936 and October 1937 - September 1993.

2 Actual period of record included April 1931 - August 1931, October 1932 - December 1979, and October 1984 - September 1998.

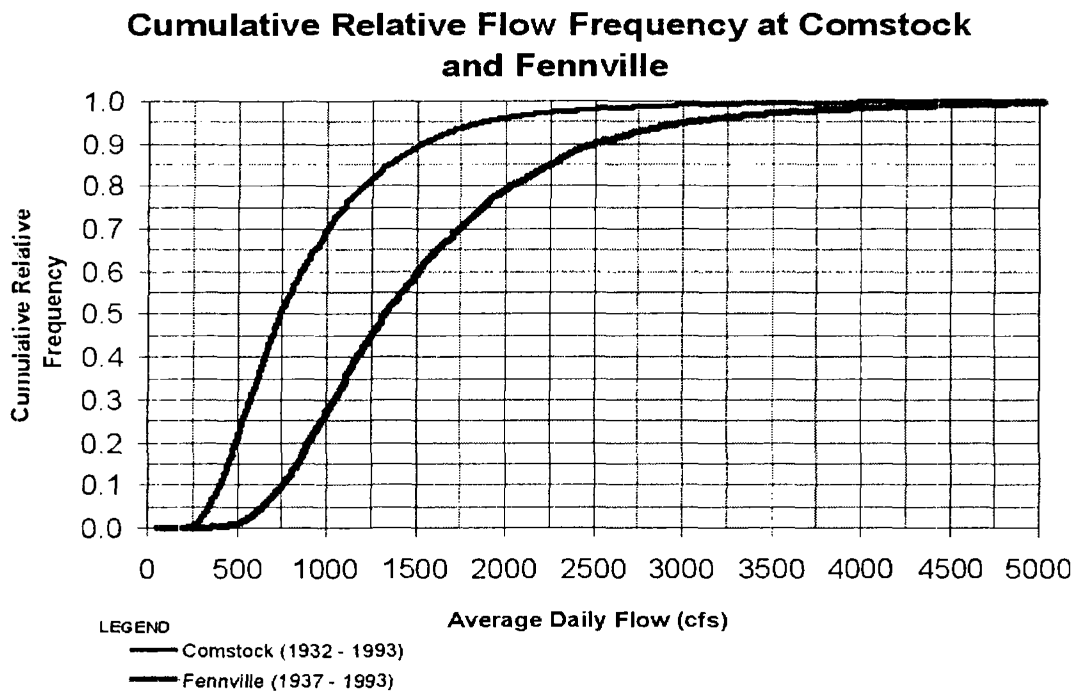
The USGS data also show that on an average annual basis the drainage yields are relatively consistent, ranging from 0.89 cubic feet per second per square mile (cfs/mi^2) at Comstock to 0.93 cfs/mi^2 at Fennville. Similarly, during March the drainage yield is 1.4 cfs/mi^2 at both Comstock and Fennville, and during August low flow conditions are 0.57 cfs/mi^2 at Comstock and 0.59 cfs/mi^2 at Fennville. The equivalent yields within the respective drainage areas mean that the ratio of the average daily flows at the two locations are proportional to the ratio of the drainage areas, which, given the 590 mi^2 difference in drainage areas, is indicative of similar watershed characteristics upstream and downstream of Comstock.

At the Comstock gage, the [redacted]. The maximum daily mean flow was recorded on April 8, 1947, at 6,830 cfs. The minimum daily mean flow was recorded on August 7, 1934, at 185 cfs (Blumer et al., 1999).

At the Fennville gage, the annual runoff averages 12.6 inches. The maximum daily mean flow was recorded on April 6, 1947, at 10,800 cfs. The minimum daily mean flow was recorded on August 19, 1976, at 50 cfs, due to shutting off flow at Lake Allegan Dam (Blumer et al., 1994).

At the Portage Creek gage near Kalamazoo, the annual mean discharge is 41.2 cfs (representing water years 1965 through 1998). This gage is located near the Lovers Lane bridge (Blumer et al., 1999). At the gage, the maximum daily mean flow was recorded on May 31, 1989, at 257 cfs. The minimum daily mean flow was recorded on September 23, 1994, at 17 cfs (Blumer et al., 1999).

Throughout the historical flow record, the [redacted]. Cumulative relative frequency distributions for daily mean flow data are provided for the Comstock and Fennville gages in the figure below. The shapes of those curves indicate that most of the time the daily mean flows are within a relatively narrow range, [redacted]. For example, at Comstock the median flow (which would be exceeded 50% of the time) is 742 cfs, the 80% exceedance flow (which would be exceeded 80% of the time) is 494 cfs, and the 20% exceedance flow (which would be exceeded 20% of the time) is 1,200 cfs. The range of flows between the 80% exceedance and 20% exceedance is 706 cfs, indicating that 60% of the time daily flow at Comstock would remain within a range of 706 cfs about a median of 750 cfs. The data at Fennville exhibit a similar trend. The steadiness of flow can be attributed to largely rural watershed characteristics as well as the numerous impoundments along the river, which tend to slow stormflow and dampen large peaks in flow. It is also important to note that both gages are downstream of large, operating dams which regulate flow and remove the influence of local high-runoff events.

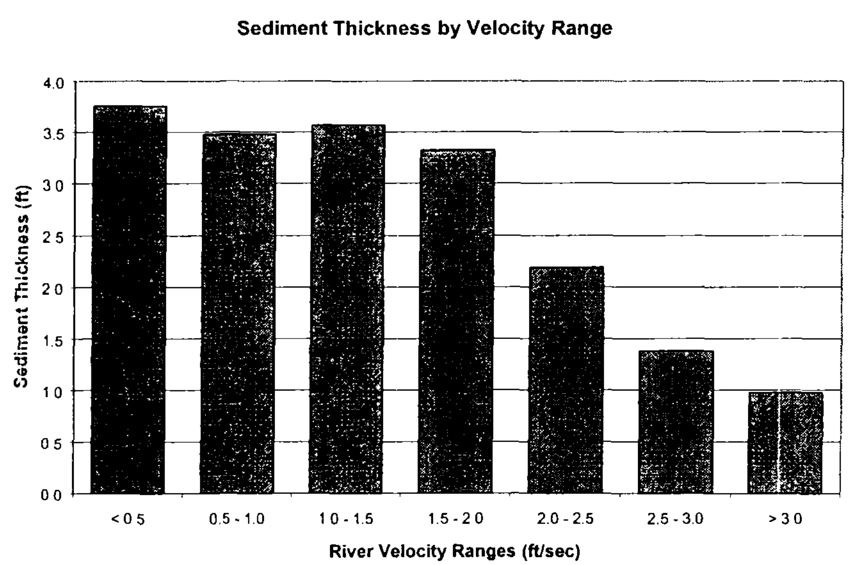


The effect of flow regulation is evident by comparing USGS peak flow data to daily mean flow data. Peak flow measured by the USGS is the maximum flow recorded for a 15-minute period, while daily mean flow is the average of all 15-minute recorded flows for a 24-hour period. In a highly variable river the peak flow will be reached quickly in a day, flow will subside, and the daily mean flow for that day will be considerably less than the instantaneous flow. A comparison of annual peak flows (the highest 15-minute recorded flow per year) to daily mean flows for the corresponding days indicates close agreement between the two parameters in the Kalamazoo River. At the Comstock gage, the difference between the average instantaneous peak flow (3,174 cfs) and the average daily flow for the corresponding days (3,064 cfs) is only 110 cfs. [redacted] At the Fennville gage the average difference between peak and daily mean flows is approximately 11% (503 cfs). The increased fluctuation at Fennville is most likely due to the presence of Swan Creek between Lake Allegan Dam and the gage, which can provide locally rapid contributions of flow from its drainage basin during widespread flood events.

> ➢ Flow is regulated by the many impoundments along the river and the largely rural nature of the watershed.

Although the smaller difference between the average instantaneous peak flow and the average daily flow at the Comstock gage would seem to indicate that the river is less responsive there than at the Fennville gage, upstream locations display generally flashier tendencies, showing increasingly higher event responsiveness as the drainage area becomes smaller and more influenced by local precipitation and quicker response times. This expectation was confirmed in a broader analysis of data done by [redacted] river based on statistical [redacted]. He applied seven indices of flow variability to flow data and rated the event-responsiveness of 119 Great Lake tributaries. Data from the Fennville gage ranked the Kalamazoo River an average of 110th out of all 119 due to its smaller relative variability between high flows and low flows compared to the other rivers. Applying the same indices to gage data from Comstock indicate a slightly more responsive river to high flow events, but still resulted in an average ranking of 105th of the 119 Great Lake tributaries included in Richards' study.

The lack of highly varying flow conditions and low susceptibility to flash floods will affect the characteristics of surface water transport of suspended solids and other constituents. In highly responsive streams and rivers, where runoff is rapid, large increases in flow can result in erosion, both of overland soil and the sediment bed. In a more stable river, large contributions of solids and other constituents resulting from overland erosion are limited to tributaries, which can be compared to discrete point sources. Concentrations of suspended solids, total phosphorus, and other particle-associated pollutants tend to remain relatively constant over the range of flows in a stable-response river like the Kalamazoo River (Richards, 1990). Even though the flow conditions lack any significant variability over time, there is enough variability in flow velocity in the different reaches of the river to have an effect on sediment deposition. The sediment is at its deepest in reaches with low velocity, and fairly thin (less than one foot deep) in the faster-flowing reaches (see figure below).



3.5 Geomorphology

Geomorphology is the study of landforms and the processes associated with the formation of landforms. This field includes the study of river erosion, landslides, glaciers, coastal processes, and generalized soil erosion. River geomorphology attempts to describe the physical processes associated with the channel shape, sediment transport, and floodplain geometry. These features are formed by a three dimensional time-dependent water movement over a mobile bed and help to define reaches of the river that have distinct physical characteristics and processes associated with them.

The Rosgen system is used to classify channel morphology. Six morphological measurements are used:

- Entrenchment ratio
- Width-to-depth ratio
- Sinuosity
- Number of channels
- Water-surface slope
- Bed material particle size

The Kalamazoo River is a dynamic landform subject to change in channel shape and flow pattern. The channel dimensions (width, depth, meander wavelength, and gradient) reflect the magnitude of water and sediment discharges. Dimensionless characteristics of the river channel and types of pattern (braided, meandering, straight) are significantly affected by changes in flow rate and sediment discharge, and by the type of sediment load in terms of the ratio of suspended to bed. The geomorphology of the Kalamazoo River is an important factor in understanding the uniqueness of each reach and providing linkages between channel characteristics and perimeter sediment. Since most major chemical elements such as PCB are adsorbed onto and transported by sediment, [redacted]

The most widely accepted method of describing channel morphology has been proposed by David L. Rosgen (Rosgen, 1996). The Rosgen system of stream classification is modeled after parameters of channel form and pattern but has the advantage of clarifying channel behavior, which is important to restoration efforts and predicting deviations from normal river condition. Under natural conditions, a given river may show significant longitudinal change in character as a result of passage from one lithologic type to another, tributary entrance, or change in landscape character; therefore, the Rosgen system is used to classify stream reaches. The Rosgen classification system has seven types ranging from A to G (see table below for a brief description of each type). In the simplified version, each type has six subclasses (between 1 and 6) that describe the size and coarseness of parent material, where 1 is bedrock and 6 is silt/clay.

The Rosgen method of stream classification, where applicable, was used as the basis to describe, express, and relate the Kalamazoo River reaches' state and characteristics from upstream of the WB/A-OU to Lake Allegan using available data that included transects, aerial photos, and digital elevation model. The classification scheme simplifies the drainage network into understandable pieces and facilitates a methodology to assess past, present, and potential future conditions among varied reaches. It should be noted that although the geomorphic classification has some value in evaluating the behavior of the river, [redacted]. Artificial sedimentation behind the dams has caused the bank material to be fine-grained, creating unique characteristics that cannot be explained by typical regional geomorphology.

The Rosgen method uses six morphological measurements for classifying a stream reach -- entrenchment ratio, width-to-depth ratio, sinuosity, number of channels, water-surface slope, and bed material particle size. The entrenchment ratio, which describes the relationship of the river or stream to its landscape, is defined as the vertical containment of the river. It is estimated by calculating the ratio of the flood-prone width to the bankfull width, where the flood-prone width is approximately the width at which the water level is twice the maximum depth and the bankfull width is the width corresponding to the maximum water level. Large entrenchment ratios indicate large floodplain in a broad valley, while small ratios are associated with steeper streams and V-shaped valleys with small floodplain.

The width-to-depth ratio is the ratio of the bankfull surface width to the bankfull average depth, in a riffle section. This parameter is an indicator of channel instability. The width-to-depth ratio is important in understanding a stream's adjustments to the water's energy in the channel, and the ability of various discharges within the channel to move sediment. [redacted]. This increase in sediment supply in combination with an ever-widening channel will eventually lead to a velocity decrease and deposition of sediment. Ultimately, this pattern of erosion and deposition is cyclical for channels with high width-to-depth ratios.

Stream channel sinuosity refers to the meandering pattern that streams acquire as they flow through the landscape. It is estimated as the ratio of stream length to valley length. These back and forth patterns are determined by water velocity and irritability of the parent soils that contain the stream channel. As the water flows through the bends created at the point of the meanders, stream power, or the energy needed to erode the stream banks, is dissipated. The lateral distance that the meanders create will, therefore, increase until enough energy is lost to establish a balance between the erosive potential of the water and the stream bank's susceptibility to erosion. Pattern adjustments, measured as sinuosity variation, are closely related to the type, size, and amount of sediment load. They are also related to bank resistance and to discharge characteristics of the stream. The degree of meandering (sinuosity) may be limited in streams located in erosion-resistant parent soils. However, channels with a moderate to low degree of meandering will still have a definable pool-riffle sequence that repeats at normal intervals of approximately five to seven stream widths. Pools (deep, scoured portions of stream where water flows slowly) and riffles (shallow rapids where water flows swiftly over gravel) are equally spaced irregularities of gradient that develop in streams. Their development appears to be a response to the sinuous movement that occurs naturally in flowing water.

The slope of water surface is a major determinant of river and stream form, structure, and performance. Slope is determined as the change in water surface elevation per unit stream length. Variations in slope result in changes in width, depth, and water velocity. Changes in bed elevation from a riffle to a pool affects flow properties. Flow accelerates from pool to riffle while velocity decreases from riffle to pool.

The bed material particle size used in Rosgen's classification is the dominant bed surface particle size, determined in the field by a pebble-count procedure (Wolman, 1954) or as modified for sand and smaller sizes.

Rosgen Classification System	
Stream Type	**Description**
A	Single-threaded channel, entrenched, low width/depth ratio, low sinuosity
B	Single-threaded channel, moderately entrenched, moderate width/depth ratio, moderate sinuosity
C	Single-threaded channel, slightly entrenched, moderate to high width/depth ratio, high sinuosity
D	Multiple channels, very high width/depth ratio, low sinuosity
DA	Multiple channels, low width/depth ratio, low to high sinuosity
E	Single-threaded channel, slightly entrenched, very low width/depth ratio, very high sinuosity
F	Single-threaded channel, entrenched, moderate to high width/depth ratio, moderate sinuosity
G	Single-threaded channel, entrenched, low width/depth ratio, moderate sinuosity

Classifications for Channel Material	
Number	**Material**
1	Bedrock
2	Boulders
3	Cobble
4	Gravel
5	Sand
6	Silt/Clay

The study portion of the Kalamazoo River (from upstream of the WB/A-OU to Lake Allegan) is divided into five broad reaches that contrast geomorphologically. Along the reach immediately downstream from Morrow Dam to the Portage Creek confluence [KPT-1 to KPT-20], the Kalamazoo River can be classified as Type C5 or Type B5. The section of the river which starts from Morrow Dam and ends after KPT-10 where the river begins to narrow, is a slightly entrenched, meandering, sand-dominated with occasional gravel and silt/clay, pool-riffle channel with a well-developed floodplain. This section is typified with low sinuosity (roughly 1.5), broad valleys, very gentle gradient of about 0.3%, and displays high width-depth ratios due to the depositional characteristic of the river and the active lateral migration tendencies. On the average the width-depth ratio is roughly 50. Sediment probing data collected in 1993 show 1 to 8 feet of sediment, which suggests that deposition is occurring within this section [up to KPT-10]. It is unclear from the transects whether there are any areas of scour. This section of the river is classified as Type C5.

The section of the river downstream of KPT-10, where the river begins to narrow to the confluence with Portage Creek (KPT-20), may be denoted as Type B5. This section is more entrenched and occurs in a narrow, moderately steep valley with gentle sloping side slopes, and has moderate width-depth ratio. Information gathered from the transects show there are obvious depositional areas near the confluence with Portage Creek, but scour areas are unclear. The sediment and bank material are the same as described for Type C5. The major difference between Type C5 and Type B5 is the entrenchment ratio, which is higher for Type C5. Also the pool-riffle sequence for a Type C5 stream is 5 to 7 bankfulls, whereas it is 4 to 7 bankfulls for Type B5.

Except for some few isolated sections that exhibit a multiple channel system, most of the reach between the Portage Creek confluence to Main Street, Plainwell [KPT-20 to KPT-56], can be considered a Type B5 or Type C5. Compared to the previous reach, this reach is more entrenched, has lower sinuosity (about 1.4), and higher width-depth ratios. The bank material still consists of mostly medium to coarse sand with gravel, however, the amount of silt and clay increases with distance downstream. Based on sediment probing data, there does not appear to be much deposition until KPT-50. The multiple channel sections have relatively low gradients, deep and narrow channels, and can be classified as Type DA.

Between Main Street, Plainwell and the former Plainwell Impoundment [KPT-56 - KPT-67], the Kalamazoo River can also be described as Type B5 or Type C5. However, the bank materials in this section of the Kalamazoo River are typically silt and clay due to the artificial sedimentation resulting from the dams. The channel sediments are still mostly sand and gravel. Based on sediment probing data, there is only a couple of feet of sediment in this reach until near the Plainwell Dam [KPT-67], where there is up to 5 feet of sediment.

In the reach from the Plainwell Dam to the Otsego Dam [KPT-68 - KPT-94], there are an extensive number of sand/silt bars, which give the river a multiple-channel appearance (Type DA). The sinuosity increases within this stretch of the river, and the transects indicate that deposition is occurring in these areas as the result of a flatter slope. There does not appear to be any scour occurring in this area. The short section between the Otsego City Dam and the former Otsego Impoundment can be considered as type B5 or C5 channel consistent with previous descriptions.

The Kalamazoo River reach between the former Otsego and Trowbridge impoundments is very similar to the reach between Main Street, Plainwell and the former Plainwell Dam, and can also be classified as Type B5 or Type C5. Compared to the stretch leading up to the Plainwell Dam, the river between the former Otsego and Trowbridge impoundments has slightly higher entrenchment ratios (less entrenched), greater slope, and greater sinuosity of approximately 1.8.

3.6 Soils and Floodplain Soils

> ➢ The floodplains of the Kalamazoo River between Morrow Dam and Lake Allegan are typically very narrow. Therefore, very little floodplain soil exists within the Site.

The soils within the Site have been characterized by the U.S. Department of Agriculture Soil Conservation Service (USDA-SCS). General soil associations and soil complexes in Kalamazoo and Allegan counties are described in the respective county soil surveys (USDA-SCS, 1979; USDA-SCS, 1987). In general, the soil in the area is described as ranging from nearly level to steep, and from poorly drained to well-drained. The soils have loamy to sandy subsoils formed in glacial outwash and moraine deposits.

In Kalamazoo County, the general soil type in the Kalamazoo River valley is Oshtemo-Kalamazoo-Glendora. This type of soil is nearly level to undulating, well-drained or very poorly drained, with a sandy subsoil or a loamy and sandy subsoil. This soil type was formed in glacial outwash and sandy morainic deposits (USDA-SCS, 1979).

In Allegan County, there are a number of soil types in the Kalamazoo River valley, with the majority being of the Glendora-Adrian-Granby and Oakville associations. The Glendora-Adrian-Granby Association is nearly level, having poorly drained and very poorly drained soils that were formed in sandy and organic material, commonly found on floodplains, outwash plains, lake plains, and till plains. The Oakville Association is nearly level to steep, with moderately well-drained soils formed in sandy material commonly found on outwash plains, lake plains, dunes, moraines, and beach ridges. The other soil types found have similar characteristics. At the mouth of the Kalamazoo River, the soils consist of dune land and beaches (USDA-SCS, 1987).

~~The soils found in the three state-owned former impoundments are poorly drained and well suited for wetlands vegetation.~~ These soils are actually sediment that had accumulated in the impoundments through the early 1970s, before the MDNR permanently opened the dams, lowered the impoundments, and exposed the sediments. The soils in the former Plainwell Impoundment are a combination of Sloan silt loam, ponded aquents and histosols, and Glendora loamy sand. The soils in the former Otsego and Trowbridge impoundments are mostly Sloan silt loam.

Sloan silt loam is nearly level, very poorly drained, and found in floodplains. Glendora loamy sand is nearly level, poorly drained, frequently flooded and ponded, and is located on floodplains along rivers and streams. The marshes and swamps along the river tend to contain aquents and histosols, which are poorly drained, nearly level soils (USDA-SCS, 1987). Appendix D presents additional information regarding the soils in these former impoundments. [redacted]. Most of the floodplain soils within the study area deposited under typical conditions are within the forest land immediately surrounding the river, and tend to be high in organic content from detritus. Forest surrounds much of the available floodplain, particularly around low-lying forested wetlands and sections of the river containing braided and meandering channels. Where the floodplain is not wooded, aerial photos show evidence of coarse material (i.e., a gravel bar within a braided channel) indicative of a transient sediment bed not conducive to the long-term deposition of flood-borne sediment or PCB.

By far the largest areas and volumes of floodplain soils are found within the three former impoundments. The soils in these areas, however, were not deposited under typical floodplain conditions or mechanisms and, therefore, are not representative of historical solids and PCB transport to the floodplain. These soils are, for the purposes of the RI, [redacted]n.

3.7 Exposed Sediment in State-Owned Former Impoundments

This section reviews the physical characteristics of the exposed sediment areas, identifies physical and biological characteristics of identified wetlands in the former impoundments, and assesses alterations of the Site caused by drawing down the impoundments.

> ➢ Drawdown of the impoundments at Plainwell, Otsego, and Trowbridge released over 1 million cubic yards of PCB-containing sediment and reversed the positive effects of ongoing natural recovery processes.

The Plainwell, Otsego, and Trowbridge dams originally were constructed in the early 1900s for the production of hydroelectric power. Power generation ceased at these dams in December 1965 and the dams were deeded to a predecessor of the MDNR by Consumers Power Company in September 1967. The MDNR drew down the three impoundments by permanently opening the dams in the early 1970s. In 1987, the MDNR removed the three dams down to their sill levels. The MDNR retains ownership of the remains of all three dams. Each of the former impoundments is further described in Section 1.4.

MDEQ = pre Argument

[redacted] result of the drawdown of water in the impoundments, the [redacted] that the scope, complexity, and duration of investigating [redacted] Physical impacts resulting from these drawdown activities include altered channel hydraulics, increased sediment erosion and transport, and habitat modification. This, in turn increased PCB exposure and potential risk, increased RI/FS and remedial action scope and complexity, and reversed or slowed the effects of ongoing natural recovery processes (see Appendix F).

original dams interrupted rivers natural tendency TO

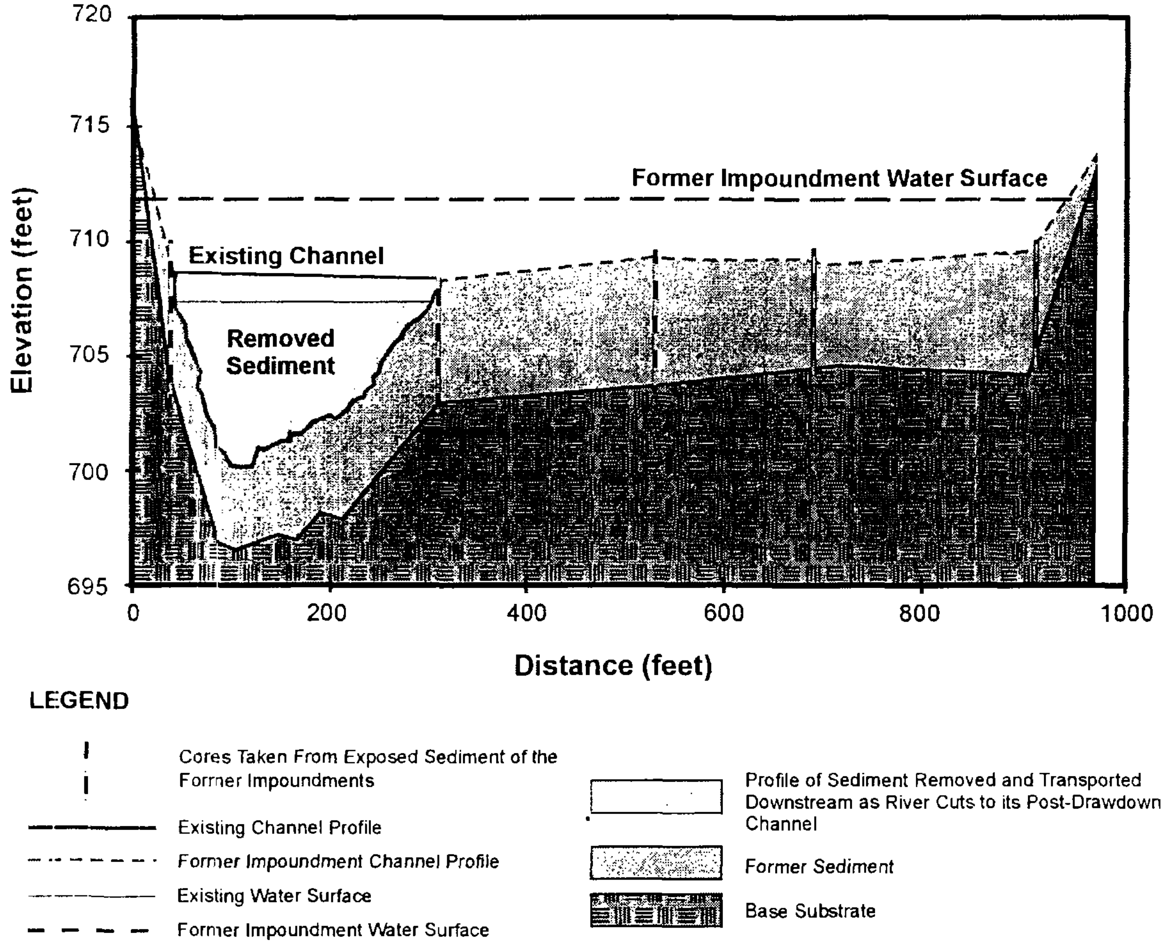
Rivers naturally tend to approach equilibrium states or near-equilibrium states over time. Drawdown of the impoundments to their sill levels interrupted this natural tendency by drastically altering the Kalamazoo River's channel hydraulics (Voskov et al., 1991). Hydraulic head was reduced by about 5 to 10 feet at each dam (Donohue & Associates, 1990), and the impoundments were changed from sediment depositional environments to unstable erosional environments with hundreds of acres of newly exposed former sediments and floodplains. [redacted] areas are now susceptible [redacted]

The release of impounded water resulting from the drawdowns increased flow velocities near the dams by factors ranging from 5 to 15 (GZA-Donohue, 1990). The high velocities increased erosion of the channel bed and side slopes, resulting in downstream transport and dispersal/redistribution of PCB-containing sediments (Anderson, 1991; Anderson and Creal, 1989). The figure below presents a representative channel cross-section showing both pre- and post-drawdown channel profiles and water surface levels, as well as the estimated cross-sectional area of former sediment that was removed and transported downstream. [redacted]

MDEQ = pre Argument

A total of approximately 1.1 million cubic yards (cy) of PCB-containing sediment were displaced from the three impoundments as a direct result of the MDNR permanently opening the dams. These sediments, transported downstream and redeposited, contained approximately 14,800 kilograms (kg) of PCB, a significant portion of the PCB mass currently residing in the sediments of Allegan City Impoundment and Lake Allegan (see Appendix B).

Former Impoundment Pre-and Post- Drawdown Channel Cross-Section



Impoundment drawdown affected potential human and ecological exposure by changing the areas from flooded, aquatic environments to exposed, terrestrial environments. These actions interrupted and, in fact, reversed several years of natural burial of PCB by progressively cleaner sediment. By exposing hundreds of acres of former sediments, drawdown of the impoundments caused an increased potential in PCB bioavailability and created new exposure pathways for terrestrial biota receptors that were able to colonize the drained areas, thereby potentially impacting related ecological food chains. In addition, the downstream transport of PCB-containing sediment increased PCB exposure to aquatic biota below the dams. By releasing sediments formerly retained in the impoundments, the areal extent of PCB distribution downstream of each impoundment was increased, thereby extending the total length of river and shoreline where potential human and ecological exposure to PCB could occur.

3.7.1 Physical Characteristics

> - The exposed sediment in the three former impoundments was investigated in 1993 and 1994.
> - Samples were taken from 159 locations.

This subsection summarizes the results of investigation activities conducted in 1993 and 1994 to physically characterize the exposed sediment areas. Further details regarding the exposed sediment investigation are provided in *Draft Technical Memorandum 12* (BBL, 1994d). Field data from the investigation include the thickness of exposed sediment, soil descriptions, and surveyed coordinates and elevations at 159 sample locations collected along transects throughout the three former impoundments. These data were used in conjunction with historical data (e.g., topographic maps prepared for GZA-Donohue [1990]) to assess the physical conditions of the exposed sediment areas.

The exposed sediments are located within wide, flat floodplains in the former impoundment areas. Soils within the three former impoundments vary considerably with respect to soil type, total solids content, color, and texture. Many of the transect cores encountered native soils beneath the exposed sediments. Observed native soils ranged from brown fine sand and silt, to brown and orange coarse sand and gravel, to peaty substrate, and varied as a function of location within the former impoundments. The native soils were notably void of gray clay residuals. Former impoundment sediments included various sands and silts, and areas of gray to gray and brown clay and silt.

Sediment accumulation in the former impoundments was greatest in areas immediately adjacent to the present Kalamazoo River channel and in other areas that facilitated deposition during the historical period of impoundment.

3.7.1.1 Former Plainwell Impoundment

Exposed sediments in the former Plainwell Impoundment cover an area of approximately 59 acres. The Plainwell Dam formerly impounded water to an elevation of 712 feet National Geodetic Vertical Datum (NGVD) (Evans, 1966), and the exposed sediments generally lie within the area defined by this elevation. The exposed sediments frequently were observed to be covered by a few inches of brown, silty to sandy soil, often mixed with organic material. The thickness of the former sediments at all three former impoundments ranged from several inches in the areas at the upstream end to several feet in areas near the dam sill. The average thickness of the former sediments in the former Plainwell Impoundment was approximately 3.8 feet. Areas of gray clay deposition were observed in locations where the former impoundment water was relatively shallow or where backwater conditions existed. The volume of the exposed sediments was estimated to be approximately 360,000 cy (see Appendix G).

3.7.1.2 Former Otsego Impoundment

The Kalamazoo River within the former Otsego Impoundment is approximately 18,000 feet long, and covers an area of approximately 77 acres. Prior to drawdown, the Otsego Dam impounded water to an elevation of 683 feet NGVD (Evans, 1966). Several physical features in the former Otsego Impoundment influenced the depth and type of exposed sediment observed. Data from transect OES2 cores suggested that an abandoned bridge abutment facilitated the deposition of gray clay immediately downstream. Relatively thick deposits (i.e., >4.5 feet) of sediment containing gray clays were observed in narrow bands adjacent to the current river channel. The average thickness of sediments throughout the former impoundment was approximately 4.4 feet, and the volume of remaining former sediment was estimated to be 540,000 cy (see Appendix G).

3.7.1.3 Former Trowbridge Impoundment

The meandering reach of the Kalamazoo River within the former Trowbridge Impoundment – the largest of the three former impoundments -- covers approximately 25,000 feet and includes the confluence with the Schnable Brook. The exposed sediments cover an area of approximately 374 acres. The Trowbridge Dam formerly impounded water to an elevation of 669 feet NGVD (Evans, 1966). The former Trowbridge Impoundment exhibits many of the same depositional trends observed in the former Otsego Impoundment. Brown to light brown and orange sand and silt characterize the higher elevation soils outside of the former impoundment and the native soil beneath the sediment. Gray clay and silt were observed in the depositional areas of the former impounded water where sediment accumulation historically was greatest. Depositional areas include the wider channel areas where still water or backwater would have occurred. Localized deposition of sediments from Schnable Brook at its confluence with the Kalamazoo River is reflected in surficial sediments that consist of brown sand and silt overlaying sediment containing gray clay. The average thickness of the exposed sediments throughout the former Trowbridge Impoundment is approximately 3.1 feet, and the volume of exposed sediment is estimated to be approximately 1,900,000 cy (see Appendix G).

3.7.2 Former Impoundment Wetland Assessment

Wetland areas within the state-owned former impoundments were identified and characterized as part of a wetland assessment conducted in 1994. The wetland identification was performed in two steps. The first step consisted of gathering existing information to preliminarily identify potential wetlands, while the second step was a site visit to evaluate the accuracy of the information collected in step one. Existing information reviewed in the first step included:

- USFWS National Wetlands Inventory (NWI) maps for the Otsego (USFWS, 1981h) and Merson (USFWS, 1981f) quadrangles;
- USGS topographic maps for the Otsego and Merson quadrangles;
- USDA-SCS Soil Survey for Allegan County (USDA-SCS, 1987);
- 1991 aerial photographs (Lockwood, 1991); and
- 1992 DCS (BBEPC, 1992).

A detailed discussion of the wetlands assessment is provided in Appendix D, and additional information and updates are provided in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). Brief summaries of the wetlands identified within each of the former impoundments follow.

There are two NWI-mapped wetlands within the limits of the former Plainwell Impoundment. One is classified as palustrine forested wetlands, and the other as palustrine emergent wetlands. Together these total approximately 9 acres (USFWS, 1981h).

There are six NWI-mapped wetlands within the limits of the former Otsego Impoundment. These wetlands consist of palustrine emergent and palustrine forested wetlands (USFWS, 1981h). Together, they total 37 acres.

The NWI maps (USFWS, 1981h; 1981f) identifies a total of 65 wetlands covering approximately 430 acres within the limits of the former Trowbridge Impoundment. These wetlands are primarily low-lying areas surrounding hairpin curves of the river. Wetland types in this stretch consist of palustrine emergent, palustrine forested, and palustrine scrub/shrub wetlands.

3.8 Ecology

> ➢ The area hosts two federally endangered species, two federally threatened species, and one federal candidate species. The state of Michigan classifies nine species as threatened or endangered and eight as species of concern.

The Kalamazoo River watershed is within the Michigan/Indiana Till Plains ecoregion, which features an irregular landscape of glacial plains, rolling hills, valleys, small lakes, and ponds. Dominant vegetative cover characteristic of this ecoregion and the Kalamazoo watershed includes cultivated croplands and pastures, wetland complexes, and woodlands of oak-hickory and maple-beech climax communities. Overall, seven distinct types of native plant communities are present, with associated mixed transition zones between and among them. The seven community types can be summarized as follows (MDNR, 1981; KRWC, 1998):

- *Dry southern hardwood forest* - features forests of dry upland sites with bur, black, or white oak dominant;
- *Mesic southern hardwood forest* - features forests that occur in moist soils with beech and sugar maple dominant;
- *Wet lowland forest* - features forests dominated by willow, cottonwood, silver maple, and ash;
- *Sphagnum bog* - features wet, open, and treeless areas with heathlike shrubs and sphagnum moss dominant;
- *Grassland-savanna complex* - features a combination of prairies, sedge meadows, and savannas that are treeless or have scattered tree cover and are dominated by grasses or wet/dry sedges;
- *Marsh and emergent aquatic community* - features treeless areas where the water table is above the soil surface during most of the growing season; and
- *Submerged aquatic community* - features communities that are essentially lakes, ponds, and streams and dominated by plants below or at the water surface.

While each of these communities can be observed within the Kalamazoo River watershed, the dominant forest and savanna communities of presettlement times are now a fragmented patchwork of smaller woodlots (typically 100 acres or less), wetlands, active and abandoned agricultural lands, urban and suburban areas, and remaining relics of other native communities (Brewer et al., 1991). The largest remaining tract of relatively unmodified land is within the 45,000-acre Allegan State Game Area, which includes large wetland and marsh areas within the floodplain below Lake Allegan (e.g., Ottawa Marsh and Swan Creek Marsh).

The Kalamazoo River supports a variety of wetland types ranging from small riparian wetlands to extensive hardwood swamps and emergent marshes. NWI maps provided by USFWS indicate a wide variety of wetland features within the Kalamazoo River, summarized here by river reach (NWI maps cited here are provided in Appendix D of the 1992 DCS):

- *Portage Creek immediately upstream of the confluence with the Kalamazoo River* - is a palustrine wetland (USFWS, 1981d);

- *Morrow Dam to the Otsego City Dam, including the former Plainwell Impoundment* - is classified as a permanently flooded, lower perennial riverine system with an unconsolidated bottom (USFWS, 1981b; 1981d; 1981e; 1981h);

- *Former Otsego Impoundment* - is classified as a permanently flooded, lower perennial riverine system with an unconsolidated bottom. The 3,000 feet upstream of the former Otsego Dam is classified as diked/impounded, permanently flooded palustrine wetland with an unconsolidated bottom (USFWS, 1981h).

- *Former Trowbridge Impoundment* - is classified as a diked/impounded, permanently flooded, limnetic, lacustrine system with an unconsolidated bottom (USFWS, 1981f; 1981h).

- *Trowbridge Dam to Allegan City Impoundment* - the first 600 feet after the Trowbridge Dam is classified as a permanently flooded, upper perennial riverine system with an unconsolidated bottom. After that, until the Allegan City Impoundment, the river is classified as a permanently flooded, lower perennial riverine system with an unknown bottom (USFWS, 1981f; 1981j).

- *Allegan City Inpoundment* - is classified as a diked/impounded, permanently flooded, limnetic, lacustrine system with an unknown bottom (USFWS, 1981j).

- *Allegan City Dam to Lake Allegan Dam* - is classified as a permanently flooded, lower perennial riverine system with an unknown bottom (USFWS, 1981j).

- *Lake Allegan* - is classified as a diked/impounded, permanently flooded, limnetic, lacustrine system with an unknown bottom (USFWS, 1981g; 1981j).

- *Lake Allegan Dam downstream to Lake Michigan* - with the exceptions of Kalamazoo Lake and the outlet channel, the river is classified as a permanently flooded, lower perennial riverine system with an unknown bottom and an unconsolidated bottom, depending on location (USFWS, 1981a; 1981c; 1981g). Kalamazoo Lake is classified as a permanently flooded, part limnetic and part littoral, lacustrine system with an unconsolidated bottom. The outlet channel is classified as an excavated, permanently flooded, lower perennial riverine system with an unconsolidated bottom (USFWS, 1981i).

These wetland features within the Kalamazoo River, in combination the wetland and terrestrial habitats within the riparian area, provide good habitat for many plant and animal species. Common resident game species include white-tailed deer, rabbit, ring-necked pheasant, ruffed grouse, and turkey. Relatively common fur-bearers include mink, muskrat, red fox, skunk, raccoon, woodchuck, mice, and voles. Common migratory waterfowl include mallard duck, black duck, wood duck, Canada goose, and blue-winged teal. The Kalamazoo River system is considered a warm-water fishery, dominated by pike, bass, catfish, panfish, carp, and suckers; salmon and steelhead are popular targets for anglers fishing the waters below Lake Allegan. Several tributaries are conducive to a cold-water fishery featuring brown and rainbow trout. Overall, the *Allegan State Game Area Master Plan* and the Michigan Natural Features Inventory (MNFI) for Allegan and Kalamazoo counties lists approximately 200 species of birds, 45 mammals, 20 amphibians, 75 fish, and 20 reptiles sighted within the area (Brewer et al., 1991; KRWC, 1998; MDNR, 1981; MDNR, 1993).

According to the USFWS, two federally endangered species, two federally threatened species, and one federal candidate species may occur in proximity to the Kalamazoo River within Kalamazoo and Allegan counties. The Karner blue butterfly (*Lycaeides melissa samnelis*) is an endangered species which may occur in Section 14 in Manlius Township, Section 31 of Heath Township, and Section 22 of Valley Township, all of which are in Allegan County. The Indiana bat (*Myotis sodalis*) is an endangered species which may occur in the southern three tiers of counties in the lower peninsula of Michigan. The bald eagle (*Haliaeetus leucocephalus*) is a threatened species that occurs in portions of the Allegan State Game Area (Sections 23, 24, and 25 of Manlius Township and Section 5 of Valley Township). Pitcher's thistle (*Cirsium pitcheri*) is a threatened species that may occur in Section 4 of Saugatuck Township, near the mouth of the Kalamazoo River. The eastern massasauga rattlesnake (*Sistrurus catenatus catenatus*) is a candidate species that may occur in Section 23 of Saugatuck Township, Section 9 of Valley Township, and Section 27 of Cooper Township (Czarnecki, 2000).

The habitats for these species are varied. The habitat for the Karner blue butterfly is pine barrens and oak savannas on sandy soils, which contain wild lupines. The summer habitat for the Indiana bat (the bats migrate out of the area for the winter) includes small to medium river and stream corridors with well developed riparian woods, woodlots within 1 to 3 miles of small to medium rivers and streams and upland forests. The habitat for the bald eagle is mature forest near water. The habitat for the Pitcher's thistle are stabilized dunes and blowout areas (USFWS, 2000). The habitats for the eastern massasauga rattlesnake are wet areas including wet prairies, marshes, and low areas along rivers and lakes (USFWS fact sheet, date unknown).

The MDNR runs a Natural Heritage Program, one part of which is the MNFI, an ongoing, continually updated database on Michigan's endangered, threatened, or otherwise significant plant and animal species, natural plant communities, and other natural features. There are a total of nine threatened or endangered species listed in the MNFI known to occur on or near the Site that are protected under the Endangered Species Act of 1973 (Sargent, 2000). In addition to two of the federally-listed species identified above (Karner blue butterfly and bald eagle), they are:

Plants: Zigzag bladderwort (*Utriculata subulata*), ginseng (*Panax quinquefolius*), and log fern (*Dryopteris celsa*)
Fish: Creek chubsucker (*Erimyzon oblongus*)
Birds: Prairie warbler (*Dendroica discolor*)
Insects: Ottoe skipper (*Hesperia ottoe*)
Herptiles: Spotted turtle (*Clemmys guttata*)

Also present within several sections along the river are eight species of special concern. While these species are not protected under the Endangered Species Act, the MDNR may provide recommendations regarding their protection to help prevent them from declining to the point of being listed as threatened or endangered (Sargent, 2000). These MNFI-listed species are:

Plants: Swamp rose-mallow (*Hibiscus moscheutos*)
Fish: Spotted gar (*Lepisosteus oculatus*)
Bivalves: Purple wartyback (*Cyclonaias tuberculata*)
Herptiles: Blanchard's cricket frog (*Acris crepitans blanchardi*), Eastern massasaua (*Sistrurus catenatus*), Eastern box turtle (*Terrapene carolina carolina*), Blanding's turtle (*Emydoidea blandingii*), and Black rat snake (*Elaphe obsoleta obsoleta*)

Information on protected natural areas near the Kalamazoo River was also requested from The Nature Conservancy. The Nature Conservancy works in conjunction with private property owners on a volunteer basis to identify and register natural areas and, in some cases, holds a conservation easement on property. A representative of The Nature Conservancy determined that there are no such areas in or around the Site (Wrisley, 2000).

3.9 Demography and Land Use

The following subsections provide data on demography and land use for Site investigation areas. Major population centers include the City of Kalamazoo, Kalamazoo Township, Comstock Township, and numerous smaller cities, townships, and villages. Land use for the area varies, ranging from industrial and commercial to residential, recreational, and agricultural.

Demography

1998 Populations...

- Calhoun County – 141,005
- Kalamazoo County – 229,660
- Allegan County – 101,662

In 1998, the combined population of Calhoun, Kalamazoo, and Allegan counties was estimated to be 472,327. In 1998, the population of Calhoun County was estimated to be 141,005 (in 1990, the population was 136,293), with 25.9% of the population less than 18 years old and 13.9% over 65 years old. The majority (86.8%) of the population was white. In 1998, the population of Kalamazoo County was estimated to be 229,660 (in 1990, the population was 223,411), with 24% of the population less than 18 years old and 11.2% over 65 years old. The majority (87.8%) of the population was white. In 1998, the population of Allegan County was estimated to be 101,662 (in 1990, the population was 90,509), with 29.1% of the population less than 18 years old and 12.2% over 65 years old. The majority (97.2%) of the population was white (MDCH, 1999).

Within Calhoun County, the river flows through four cities: the City of Albion (1990 population of 10,066), the City of Marshall (1990 population of 6,891), the City of Battle Creek (1990 population of 53,540), and the City of Springfield (1990 population of 5,582). The South Branch of the Kalamazoo River flows through the Village of Homer (1990 population of 1,758) (U.S. Census Bureau, 1990).

Within Kalamazoo County, the river flows through three cities: the City of Galesburg (1990 population of 1,863), the City of Kalamazoo (1990 population of 80,277) and the City of Parchment (1990 population of 1,958); the village of Augusta (1990 population of 927); and three townships: Comstock Township (1990 population of 11,834), Kalamazoo Township (1990 population of 20,976), and Cooper Township (1990 population of 8,442) (U.S. Census Bureau, 1990).

Within Allegan County, the river flows through five cities and villages: the City of Plainwell (1990 population of 4,057), the City of Otsego (1990 population of 3,937), the City of Allegan (1990 population of 4,547), the Village of Douglas (1990 population of 1,040), and the City of Saugatuck (1990 population of 954); as well as eight townships: Gun Plain Township (1990 population of 4,754), Otsego Township (1990 population of 4,780), Trowbridge Township (1990 population of 2,328), Allegan Township (1990 population of 3,976), Valley Township (1990 population of 1,145), Heath Township (1990 population of 2,297), Manlius Township (1990 population of 1,776), and Saugatuck Township (1990 population of 2,916) (U.S. Census Bureau, 1990).

Land Use

The Kalamazoo River flows through a mix of urban, agricultural, and forested areas. The City of Kalamazoo is the largest city on the Kalamazoo River within the Site. Appendix B (Volume 5) of the DCS provides land-use maps for the Site (BBEPC, 1992).

A variety of land uses exist along the Kalamazoo River…

- Industrial
- Commercial
- Recreational
- Residential
- Suburban
- Rural

Between Morrow Dam and Portage Creek (Figures 1-3 and 1-4), land use surrounding the Kalamazoo River ranges from forested wetlands to industrial. The river initially flows through forested wetlands and then into residential and secondary business areas as it enters the City of Comstock. Once out of Comstock, the river again flows through a forested area. As the river approaches and enters the City of Kalamazoo, the land use changes to industrial and recreational. Industrial land use continues to Portage Creek, with the exception of Riverview Park and Red Arrow Golf Course, located on the southern shore in the City of Kalamazoo immediately upstream of the confluence with Portage Creek.

Several industries are located adjacent to the river, which serves as a source of process water as well as a receiving water for treated discharge water. In the reach from Morrow Dam to Portage Creek, the Georgia-Pacific Kalamazoo Mill is located along the north bank of the river, the WB/A-OU, KHL-OU, and KSSS outlet are located on the south bank, and Davis Creek enters the river near the WB/A-OU. The former King Mill is located to the south of the river. The Auto Ion Superfund Site is located to the north of the river near Mills Street, and the Michigan Disposal/Cork Street Landfill Superfund Site is located in the Davis Creek watershed. A number of other industries, some historical users or purchasers of PCB, are also located within the watershed between Morrow Dam and Portage Creek.

Land use varies between the Portage Creek confluence and Main Street, Plainwell (Figures 1-4 through 1-7). The upstream portions of this segment are in the City of Kalamazoo and support extensive industrial and residential development. Downstream of Kalamazoo, development near the river decreases as surrounding land use in the vicinity of the Kalamazoo County/Allegan County line becomes rural. As the river approaches the City of Plainwell, it flows through areas of suburban land use. Verburg Park is located on the western shore within the City of Kalamazoo. The Kalamazoo Nature Center is also located on the western shore in Cooper Township.

Many industrial facilities, including some that used or purchased PCB, are located on the river between the Portage Creek confluence and Main Street, Plainwell. Travis Creek (also known as Russell Creek) discharges to the river within this reach.

The former Plainwell Impoundment extends downstream from Main Street, Plainwell, to the former Plainwell Dam (Figure 1-7). The upper areas of the impoundment are in the City of Plainwell, and contain residential, commercial, and industrial land uses. Farther downstream, outside the incorporated limits of the City of Plainwell, the former Plainwell Impoundment is dominated by rural land uses. The Plainwell, Inc. Mill is located adjacent to the river within this segment. The 12th Street Landfill OU is located adjacent to the Plainwell Dam.

Land use within the Otsego City Impoundment (Figure 1-7) is predominantly rural and residential, with limited crop and pasture lands, woodlands, and forests. Extensive braided channels and wetlands exist in this reach. Land use in the lower portion of the segment is characterized by limited residential, industrial, and commercial development. Brookside Park is located on the southern shore in the City of Otsego.

Between Otsego City Dam and the former Otsego Dam (Figures 1-7 and 1-8), the river flows through the City of Otsego, where there is considerable industrial development in the vicinity of the M-89 bridge. The downstream portion, which is rural in character, is the former Otsego Impoundment. Land use surrounding the former Otsego Impoundment includes forest, agriculture, and limited residential areas.

Land use within the former Trowbridge Impoundment (Figure 1-8) is rural with very limited development, and includes forest land, scrub/shrub vegetation areas, and low-lying wetlands.

Downstream of the former Trowbridge Dam to the Allegan City Dam (Figure 1-9), land use is largely rural and includes extensive marshy areas where the Kalamazoo River has historically meandered. Within the upper marshy area, land use is almost entirely forest. Continuing downstream toward Allegan, land use changes from rural to suburban to urban, but still contains forested areas and areas of scrub/shrub. There is limited development along the river until it flows through the City of Allegan and into the Allegan City Impoundment. Adjacent to the Allegan City Impoundment, land use includes residential, commercial, industrial, and recreational uses. Waterfront development includes public park areas.

Downstream of the Allegan City Dam, the Kalamazoo River is impounded to form Lake Allegan (Figures 1-9 and 1-10). There is considerable recreational development along the southern shoreline, including public boat launches and picnic and recreation areas. The Allegan County Fairgrounds are located adjacent to the river near the headwaters of Lake Allegan. Land use surrounding this main body of the lake is almost completely forested with increasing residential development on both the north and south sides. The Rockwell International Superfund Site is located on the banks of the river in the headwaters of Lake Allegan.

Between Lake Allegan Dam and Lake Michigan (Figures 1-11, 1-12, and 1-13), most of the river setting is very rural. Land use includes forest with extensive marshes over about two-thirds of the distance. Included in the marshes are the Allegan State Game Area as well as privately owned facilities that are used extensively for recreation including hunting and fishing. Within the Ottawa Marsh, bald eagles have been observed and have successfully nested. Toward Lake Michigan, the river flows through the Village of Douglas and the City of Saugatuck, and supports residential and commercial land use. The shores of Kalamazoo Lake are largely developed and support recreational boating and fishing uses.

Portage Creek from Alcott Street to its confluence with the Kalamazoo River flows through the urban setting of the City of Kalamazoo (Figure 1-4). Industrial, residential, commercial, and recreational land uses are interspersed along the creek's route to the Kalamazoo River. The majority of the creek's route is through residential neighborhoods, and at least one large park (Upjohn Park, south of Vine Street) is situated adjacent to the creek. Commercial and industrial development exists in the general vicinity of the creek's confluence with the Kalamazoo River. The Allied OU, former Bryant Mill, and former Monarch Mill are located upstream of this section of the creek.

Section 4

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

Section 4
Nature and Extent

Inside Section 4 – Nature and Extent of Contamination in the Kalamazoo River System

Multiple lines of evidence show that the Kalamazoo River is recovering through natural processes. PCB concentrations in all media are significantly lower than they were at their peak in the 1970s.

Eroding riverbanks in the MDNR's former impoundments are a significant remaining source of PCB to the Kalamazoo River.

River-wide results

- Over 5,000 samples were analyzed for PCB and other chemicals in sediment, soil, water, and biota.
- There are no "hot spots" (small areas of sediment that contain a disproportionately large amount of PCB).
- Focused sampling in 2000 shows data consistent with earlier findings.

Sediment Investigation

- Distribution of PCB is determined in part by total organic carbon concentrations, particle size distribution, depth of sediment, and water velocity.
- Surficial concentrations are low – 97% of PCB results were below 10 mg/kg.
- Drawdown of the three MDNR-owned impoundments had a significant impact on PCB distribution in sediment.

Surface Water Investigations

- PCB concentrations are low, with no PCB detected in 74% of surface water samples collected in 1994.
- Concentrations are influenced by the combined effects of temperature, flow, and total suspended solids.
- Movement through the water column is the primary mode of PCB transport.

Biota Investigation

- Concentrations of PCB in fish and other biota are directly related to the amount of bioavailable PCB.
- PCB tend to accumulate in the fatty tissues of fish, therefore, the amount of fat (called lipids) in fish is an important factor in measuring PCB exposure.

(not issued in PRP whole-fish Trend analysis

4. Nature and Extent of Contamination in the Kalamazoo River System

This section presents and interprets the results of investigations designed to identify the nature and extent of PCB contamination at the Site. Those investigations include the assessment of PCB distributions in:

- Floodplain soils;
- Exposed sediment upstream of the former Plainwell, Otsego, and Trowbridge dams;
- River sediment;
- Surface water, and
- Biota, particularly fish.

In addition to measuring PCB levels, other measurements were made to develop an understanding of the factors affecting the distribution, transport, bioaccumulation, and fate of PCB within the river system. Finally, this section reports on the results of the investigation into the sources of PCB to the Kalamazoo River, past and present.

Section Summary

The results of numerous investigations were used to identify and describe the nature and extent of PCB contamination in the Kalamazoo River system. These investigations found:

- There are no "hot spots" in the river sediment; 76% of surface sediment samples contained less than 1.0 mg/kg PCB.
- The majority of PCB-containing sediment (70%) has settled in Lake Allegan.
- The Kalamazoo River has not transported significant amounts of PCB or other sediment contaminants to its floodplains.
- A substantial amount of PCB is contained in the exposed sediment of the former impoundments. Because these sediments were deposited near the peak of PCB use in the watershed, their surface contains substantially higher concentrations of PCB than are found in existing river sediment.
- Voluntary response actions at KRSG mills, OUs, and related areas have significantly reduced the actual and potential loading of PCB to the river system.
- Multiple sources of PCB have contributed to the Site, including non-paper sources such as various industrial and municipal discharges. These findings are based on several lines of evidence, including the "fingerprints" of the types of PCB found in sediment and fish. Approximately 50% of PCB measured in fish originate from PCB sources other than paper recycling.

Though upstream of the Site and the KRSG properties, this section also addresses the nature and extent of PCB contamination in Morrow Lake. The investigation revealed that the transport of PCB and sediment from Morrow Lake significantly influences the bioavailability of PCB in downstream areas.

4.1 Floodplain Soils

> ➢ Floodplain soils outside of the former impoundments are not areas of concern.

?

Based on results of the floodplain soils investigation, the MDNR concluded that the Kalamazoo River has not transported significant amounts of PCB or other chemicals to its floodplains (Cornelius, 1994). The investigation of floodplain soils is described in Section 2.3 of this report, and the results are discussed in *Technical Memorandum 3* (BBL, 1994c) and *Addendum 1 to Technical Memorandum 3* (BBL, 1996b). This section presents a summary of the results.

4.1.1 PCB in Floodplain Soils

> ➢ 87% of floodplain soil PCB samples either were non-detect or less than 1.0 mg/kg.

PCB either were not detected or were detected at very low concentrations in Kalamazoo River and Portage Creek floodplain soil samples. Of the 73 floodplain soil analyses for PCB from upstream of Lake Allegan (exclusive of the sediments within the former Otsego Impoundment), 55% were reported as nondetects and 32% as less than or equal to 1.0 mg/kg. The remaining 13% were accounted for by seven samples with reported PCB concentrations in the range of 1.0 to 2.0 mg/kg and three observations between 2.0 and 3.0 mg/kg. The PCB concentrations greater than 1.0 mg/kg were associated either with soils immediately adjacent to the river's edge or with continually wet or submerged soils (as in the case of the 2.8 mg/kg observation along river transect KF5, downstream of the former Trowbridge Dam). These soils had a characteristically high TOC content, ranging from 7.6 to 24%.

> **Why Include Morrow Lake?**
>
> Morrow Lake is a large (1,000-acre) impoundment of the Kalamazoo River a short distance upstream of the NPL Site and all KRSG facilities; it has a larger surface area than all of the river segments from Kalamazoo to the Allegan City Dam within the NPL Site. The lake has received PCB loading, most notably Aroclor 1254, sufficient to exceed State water quality standards for PCB and to trigger the fish consumption advisories currently in effect for the lake. Moreover, the levels of PCB in sediment in Morrow Lake appear sufficient to sustain levels of PCB in the lake and downstream in excess of the State's water quality standard for many years to come. Although PCB concentrations in fish are lower in Morrow Lake than within the NPL Site, they are still many times higher than a number of the benchmarks used by the MDEQ and other regulatory agencies to represent "safe" levels for various human and ecological receptors.

The results of sampling Portage Creek floodplains indicated low concentrations of PCB in soils except for an area through which Portage Creek formerly flowed. Soil samples were collected from one transect in the Portage Creek floodplains, supplemented by five additional randomly located samples from a low-lying area on Portage Paper property below the 10-year floodplain elevation. The results of the floodplain

What are they saying?
1) Its a source? (2) cleanup w/o Morrow Lake is waste of time? (3) other?

sampling at the transect were similar to those for the Kalamazoo River. PCB were detected at concentrations greater than 1.0 mg/kg in only one sample, a 2.1 mg/kg sample collected at the creek's edge. Four of the five random samples contained PCB concentrations ranging from 0.62 to 2.0 mg/kg. The fifth sample contained a reported PCB concentration of 32 mg/kg at the 0- to 6-inch depth interval and 12 mg/kg at the 6- to 12-inch interval. However, the surface elevation of this sampled location was lower than all but one of the other sampled locations. In December 1995, three additional soil cores were collected near this fifth sample location to further characterize the PCB distribution in this area. Total PCB concentrations of all additional core samples ranged from an estimated 0.18 mg/kg in one sample at the 12- to 18-inch depth interval to 57 mg/kg in a sample at the 0- to 6-inch interval. Observations that the PCB-containing subsurface soils were below the water surface of the current channel and a review of available records indicated that these soils are located in a former alignment of the Portage Creek channel, which once meandered in this area. The former channel, which now is located entirely on industrial property, is not representative of deposition on the floodplain along the creek. For example, the average surface PCB concentration within the former channel is 42 mg/kg (n = 3) while the average surface PCB concentration for the samples collected outside of the former channel is 7.5 mg/kg (n = 5).

When screened against the MDNR Type B criterion (Howard, 1993) pursuant to Act 307 (which was in effect during the investigation), the sampling results for Kalamazoo River floodplain transects indicated that flooding events have not transported PCB to floodplain soils at levels that would present a risk to human health. Therefore, with the concurrence of the MDNR, floodplain areas outside of the former impoundments were eliminated as an issue of concern along the Kalamazoo River (Cornelius, 1994). The current equivalent applicable PCB criterion under Part 201 (Residential Direct Contact Criteria) (Howard, 2000) has subsequently increased to a less restrictive value, strengthening the argument that the PCB concentrations in the floodplains are not at a level that would pose concern.

4.1.2 Other Constituents in Floodplain Soils

> ➢ Floodplain soils were also analyzed for:
>
> - Pesticides
> - PAHs
> - Metals

The results of screening 10 of the floodplain soil samples for TCL/TAL constituents showed the presence of 6 pesticides, 12 polycyclic aromatic hydrocarbons (PAHs), and apparent elevated concentrations of certain metals. Based on the 1993 floodplain soils data (presented in *Technical Memorandum 3*; BBL, 1994c), the MDNR's Type B Criteria for direct contact in residential areas (which were in effect during the investigation) were exceeded in a few instances, as described below:

- Lead in sample KF3-1B, and chrysene and benzo(a)anthracene in sample KF3-1A, each taken from the river's edge of the Brookside Park transect; and
- Benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene in sample KF1-3A, from the river's edge of the Verburg Park transect.

When these same TCL/TAL analytical results for the floodplain soil samples were compared to the current MDEQ Part 201 Residential Direct Contact Criteria (Howard, 2000), a single exceedance for lead occurred at KF3-1B (455 mg/kg compared to criterion of 400 mg/kg), and the concentration of arsenic in seven out of 10 samples exceeded the criterion (maximum of 32 mg/kg compared to criterion of 7.6 mg/kg).

There are a variety of potential sources of the TCL/TAL constituents found in the floodplain soils. The pesticides can be attributed to runoff from urban landscapes or agricultural lands in the watershed; the PAHs noted above have natural and anthropogenic sources, and are typically associated with hydrocarbons (such as asphalt and motor oils); and the lead and other metals are naturally-occurring. Lead, in particular, may also derive from urban runoff during the period when leaded fuels were widely used. Consequently, there would appear to be numerous potential sources of these compounds to the Kalamazoo River.

4.2 Exposed Sediment in MDNR-Owned Former Impoundments

The investigation of exposed former sediment in the MDNR-owned Plainwell, Otsego, and Trowbridge impoundments is described in Section 2.4.4. The results of the investigation are discussed in detail in *Draft Technical Memorandum 12* (BBL, 1994d), and summarized below.

4.2.1 PCB in Exposed Sediment

> ➢ The three former impoundments contain approximately 24,900 kg of PCB in approximately 2,800,000 cy of former sediment.

In all three former impoundments, PCB concentrations tended to be highest in the uppermost layer of exposed sediment sampled, and generally decreased with depth (Figure 4-1). Arithmetic average PCB concentrations in the upper six inches of sediment ranged from 13 mg/kg for the Otsego Impoundment to 15 mg/kg in the Trowbridge Impoundment. These results generally were consistent with the former impoundment PCB sediment data obtained as part of the Terrestrial Biota Investigation (discussed in Section 2.6.2). Figure 4-2 shows exposed sediment PCB concentrations by elevation in the former impoundments. This figure illustrates that PCB are almost entirely confined to areas within the limits of the former impoundments, as the pre-drawdown water surface elevations of each impoundment generally mark the lateral boundaries of PCB extent.

Geomorphic differences among the former impoundments appear to have affected the spatial distribution of PCB within these areas. In the more channelized, higher-energy former Plainwell and Otsego impoundments, PCB concentrations decline more quickly with distance from the current river than in the wider, flatter, lower-energy former Trowbridge Impoundment, which allowed for more evenly distributed sedimentation over a wider area. Figure 4-3 presents exposed sediment PCB concentrations in comparison to distance from the riverbank. As evident in this figure, PCB concentrations exhibit considerable lateral variation across the former Trowbridge Impoundment transects. In contrast, no PCB concentration greater than 10 mg/kg was reported beyond 250 feet from the present river channel in the former Plainwell Impoundment. The highest PCB concentrations observed in transects within the former Plainwell and Otsego impoundments are located within 200 feet and 50 feet, respectively, of the present Kalamazoo River channel. There was sufficient variation such that no significant relationship ($p<0.05$) was observed between PCB concentration and distance from the riverbank for any impoundment. The data suggest that subsurface PCB concentrations increase closer to the riverbank. In addition, the thickness of PCB-containing sediment generally is greatest near the channel as a result of greater sediment deposition rates in the deeper portions of the impoundment (BBL, 1994d). These results suggest that the sediment released as a result of impoundment drawdown contained some of the highest PCB levels in the former sediment bed.

Are they implying that MDEQ is a [illegible]?

Parameter	Former Impoundment		
	Plainwell	Otsego	Trowbridge
Surface area of former sediment (acres)	59	77	374
Average depth of PCB-containing former sediment (ft)	3.8	4.4	3.1
Volume of former sediment (cy)	360,000	540,000	1,900,000
Estimated PCB mass (kg)	3,200	6,300	15,400

Based on the PCB analytical data and physical data obtained during the exposed sediment investigation, the volume of PCB-containing exposed sediment and the associated mass of PCB were estimated for each of the former impoundments. The methods are documented in Appendix G. The average depths and volumes of PCB-containing sediment, and the associated estimated mass of PCB in the exposed sediment of each former impoundment, are presented in the above table.

4.2.2 PCB Loading from Banks of Former Sediments

> ➢ Erosion of the riverbanks in the three former impoundments is the largest ongoing source of PCB to the river.

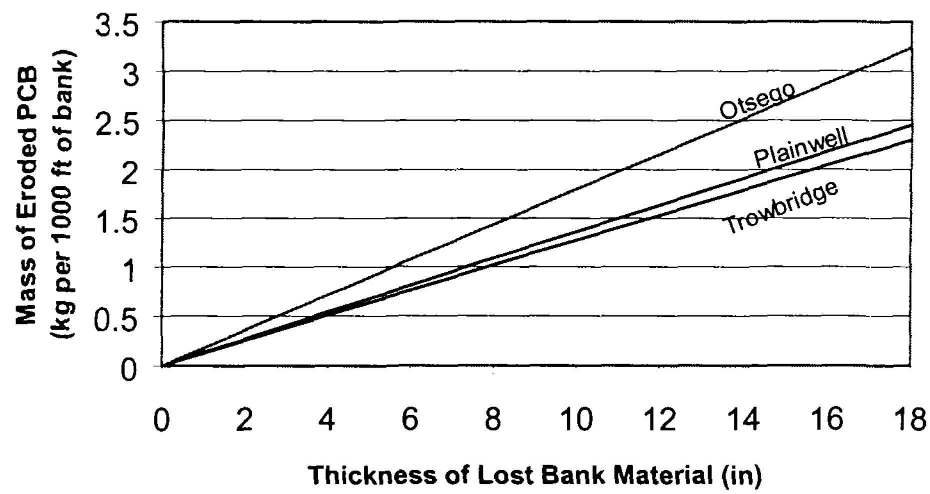
The exposed former sediments within the three MDNR-owned former impoundments appear to be the greatest remaining external source of PCB to the Kalamazoo River. An estimated 24,900 kg of PCB are contained in the approximately 2,800,000 cy of former sediments that became exposed when the MDNR drew down the Plainwell, Otsego, and Trowbridge impoundments in the early 1970s. As the impoundments were drawn down and water levels fell, the Kalamazoo River cut a new channel into the impoundment sediments, releasing the underlying PCB-containing material and dispersing it downstream (see Appendix F for more details). At the same time, approximately 1,100-acres of combined surface area in the three impoundments were drained, exposing approximately 510 acres of the former sediments on both sides of the newly cut river channel. Since drawdown in the early 1970s, and the subsequent removal of the remaining dam structures down to their sills in 1987, the river has been flowing through, and coming in contact with, this mass of PCB-containing former sediments. Consequently, the banks of the river channel have been sloughing and eroding. This is now the most significant transport pathway for ongoing external loading of PCB to the river downstream of the city of Plainwell.

Visual observations of the banks in the three former impoundments provide evidence of ongoing loading of the exposed sediments to the river, as well as some of the mechanisms involved in loading. In all three of the MDNR-owned impoundments, lengths of riverbank can be observed that are vertical or nearly vertical, and void of vegetation. The cohesive nature of the exposed sediments appears to allow them to be maintained for a certain amount of time in this vertical to near vertical repose; however, these fine-grained materials appear to overlay generally non-cohesive sandy sediments or soils. Thus, the faces of the banks appear susceptible to erosion through direct contact with the river at higher river stages, and to undercutting by erosion of the underlying non-cohesive sediments or soils. Undercutting progresses until the overlying sediments fail by slumping or calving as blocks that fall into the river. The remnants of such blocks can be seen along the toe of the banks in certain areas. The obvious existence of the loading of exposed sediments to the river, coupled with the knowledge that the exposed sediments contain levels of PCB, confirm the banks' role as a continuing source of PCB.

Based upon the RI data, the magnitude of potential PCB loading from the banks in each of the former impoundments to the river was estimated using simple assumptions. By employing the average PCB concentrations along the banks of the former impoundments and assuming a reasonable range of bank loss rates, the potential magnitude of PCB mass loading to the river was estimated. Dimensions of eroded blocks were assumed to be five feet high, the thickness was varied between 1 and 18 inches, and the length varied from 10 feet to the entire length of bank. The resulting range of estimates constrain the magnitude of potential loading of PCB by bank loss to the river. Erosion estimates methods and results are provided in detail in Appendix I. A visual summary of the results is shown in the figure below and is expanded on Figure 4-4.

The figure below shows the estimated quantities of PCB associated with an average 1,000-foot length of bank for each of the three MDNR-owned former impoundments as a function of the width (thickness) of a hypothetical block of bank material. In total, all three impoundments have about 103,000 feet of riverbank. Accordingly, these areas could contribute in excess of 20 kilograms per year (kg/yr) of PCB to the river if as little as 5% of the length of the three former impoundment riverbanks were being lost at a rate of 10 inches per year (see figure below). Based upon the observations of the banks described above, the magnitude of PCB loading was judged to be in the range of 10 kg to 100 kg/yr. Given that the estimated amount of annual PCB transport in the entire Kalamazoo River falls within that range, bank loading of PCB was judged to be highly significant and warrants more precise estimation.

Potential PCB Erosion from the Riverbanks of the Former Impoundments



To refine the estimate of bank loading, direct measurements of soil loss were sought. In 1999, the riverbanks were resurveyed at some of the locations previously surveyed during the 1993/1994 sample collection to allow comparison of both the locations and shapes of the banks and to quantify differences that had occurred over the 6-year period. PCB loading estimates for the non-point source PCB transport from the banks of these exposed sediments, based on physical measurements of the banks, are provided in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). To further refine estimates of bank erosion and PCB loading from the former impoundment banks, further survey work was performed in 2000, including the installation of erosion pins that will allow for periodic measurements of bank loss. These efforts are also described in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). The estimates contained in the Supplement are necessary to quantify the impact of the continued bank erosion.

4.2.3 Total Solids and Total Organic Carbon in Exposed Sediment

The total solids and TOC data, presented in *Draft Technical Memorandum 12* (BBL, 1994d), clarify the nature of exposed sediment found within the former impoundments. In general, total solids content of soil samples collected from within the former impoundments were significantly lower than soil samples collected from outside of the former impoundments. As may be expected, the native sandy soils located outside of the former impoundments contained significantly less TOC than the finer-grained soils within the former impoundments.

Total solids results for samples collected from the exposed sediments of the former impoundments ranged from 12% to 94%. Total solids content of the samples at locations outside the boundaries of the former impoundments were higher than locations within the former impoundments, with most greater than 75% and averaging 80%, indicative of the native sandy soils. By contrast, total solids content within the three former impoundments exhibited relatively little variability, with 64% of data between 30% and 60% solids, and an average of 53% solids.

The concentrations of TOC detected in the exposed sediment samples ranged from 0.1 to 38.8%, averaging 9.2% in the former Plainwell Impoundment, 9.7% in the former Otsego Impoundment, and 7.3% in the former Trowbridge Impoundment. Overall, TOC concentrations exhibited an inverse relationship with depth both inside and outside of the former impoundments. The concentrations of TOC detected in soil samples collected from outside of the former impoundments ranged from 0.91% to 25%, and averaged 3.9%. The difference of total solids and TOC content within and outside of the former impoundments supports the PCB data as additional factors to delineate the boundary of historical sediment deposition. ? What are they saying?

4.2.4 Other Constituents in Exposed Sediment

At one location in each of the former impoundments, one surface sample (0.0 to 0.5 feet bgs) and one subsurface sample (0.5 to 1.5 feet bgs) were collected for TCL/TAL analysis.

> ➢ The exposed sediments were also analyzed for:
>
> - VOCs
> - SVOCs
> - Pesticides
> - Metals

Four TCL volatile organic compounds (VOCs), 14 semivolatile organic compounds (SVOCs), and 6 pesticides were detected in surface and subsurface exposed sediment samples collected from the former impoundments. In February 2000, the exposed sediment TCL and TAL data were compared with MDEQ criteria (Howard, 1999), and that comparison was submitted to the MDEQ (BBL, 2000a). No TCL detections exceeded the Groundwater/Surface Water Interface (GSI) Criteria or Residential Direct Contact Criteria. TAL constituents, which are naturally-occurring inorganic compounds (e.g., metals) in soil and sediment, were detected at various concentrations in all samples. Eight TAL analytes (barium, chromium, cobalt, cyanide, mercury, selenium, silver, and vanadium) exceeded the GSI Criteria and two analytes (arsenic and lead) exceeded the Residential Direct Contact Criteria.

Since the comparison to the 1999 criteria was submitted to the MDEQ, the Part 201 criteria were again revised (Howard, 2000). No TCL compounds are detected at concentrations exceeding the revised GSI Criteria or Residential Direct Contact Criteria. Due to changes in the GSI Criteria for barium and vanadium, the detected concentrations no longer exceed the criteria. Arsenic and lead still exceed the Residential Direct Contact Criteria.

4.3 Sediment

The results of the sediment investigation, in conjunction with other data, provide valuable information regarding the nature and extent of PCB in Kalamazoo River sediment. (A detailed discussion of the sediment investigation results is contained in Appendix C.) The results show that:

- ➢ No "hot spots" exist in the Kalamazoo River sediment.
- ➢ The great majority of PCB in sediment is associated with large depositional areas in the former and existing impoundments.
- ➢ 76% of surface sediment samples had PCB less than 1.0 mg/kg, and more than 97% of surface sediment samples had PCB concentrations less than 10 mg/kg.
- ➢ Only four of 2,428 sediment samples from throughout the Kalamazoo River exceeded PCB concentrations of 100 mg/kg.
- ➢ 70% of PCB in the existing river sediment is contained in approximately 5.1 million cy of sediment in Lake Allegan.

- The spatial distribution of PCB can be highly variable over relatively short horizontal distances (i.e., on the order of tens of feet), particularly within faster flowing sections of the river. In a special study to examine this variability, samples collected about 30 feet apart had PCB concentrations differing by a factor of approximately 12.

- There are no relatively small continuous deposits of high PCB concentration sediments which contain a disproportionately large amount of PCB (i.e., there are no "hot spots");

- The horizontal and vertical distribution of PCB in the Kalamazoo River is determined in part by physical, hydraulic, and geomorphological characteristics of the river, which affect the depositional environment;

- The drawdown of the three MDNR-owned impoundments in the early 1970s had a substantial impact on the re-distribution of PCB in sediment downstream of the city of Plainwell.

The sediment data population is more log-normally distributed than normally distributed. In such log-normal distributions, while most of the data are clustered over a range of relatively low concentrations, the data indicate occasional but relatively high concentrations. Those relatively high concentrations skew arithmetic averages above the median concentration. Figure 4-5 presents the distribution of the actual PCB data along with the corresponding normal and lognormal distribution curves. The initial parameters used to generate the normal and lognormal distributions were based upon the mean and standard deviation of the actual data set. These parameters were affected by the large number of non-detect values (45%). To remove the effect of these non detect values, the normal and lognormal populations shown on Figure 4-5 were derived using the 50th percentile (median) as the estimate of the mean and the difference between the 50th and 84th percentile as the estimate of the standard deviation (Gilbert, 1987). The use of these parameters allows for the estimated distributions to be based upon reported (detected) values of the data set. As seen in the figure, the lognormal distribution more closely matches the sediment PCB data distribution than the normal distribution curve.

At Fire all non-detects were assigned the detection level instead of zero. But this method is probably ok too.

To test the usage of the lognormal distribution for sediment data, the Shapiro-Francia test was employed as outlined in USEPA guidance (USEPA, 1992). The test was performed on the log-transformed PCB data and the untransformed data. The test statistic (W') generated indicates a more lognormal distribution as it numerically approaches zero. The use of the transformed data set showed an improvement in the W' of more than two orders of magnitude (0.0062 compared to 0.82) over the untransformed data. These results confirm that the distribution of PCB concentrations in the Kalamazoo River is more appropriately represented by the lognormal distribution. ??

So what does this mean?

4.3.1 PCB in Sediment

> ➤ 97% of PCB samples from Kalamazoo River surface sediment were below 10 mg/kg.
> ➤ 43% of PCB samples from Portage Creek surface sediment were below 1.0 mg/kg.

PCB concentrations in the sediment samples collected in 1993 and 1994 were generally low and included a large number of non-detections. PCB were not detected in approximately 29% of the 645 surface samples (including 2 field duplicate samples) collected from the Kalamazoo River between Morrow Dam and Lake Allegan Dam and 47% were reported as having PCB concentrations less than

1.0 mg/kg. More than 97% of the surficial sediment PCB concentrations were less than 10 mg/kg. For the 1,783 (including 242 field duplicate samples) subsurface samples from the same portion of the Kalamazoo River, approximately 52% were reported as having nondetectable PCB and an additional 32% were reported as having PCB concentrations less than 1.0 mg/kg. In total, approximately 96% of the 2,428 Kalamazoo River sediment samples had PCB concentrations less than 10 mg/kg, and only four samples exceeded 100 mg/kg PCB. A summary of PCB concentration by depth layer is provided in Table 4-1. To allow for a direct comparison by ~~depth~~ intervals, samples from some cores were depth weighted to provide the consistent depth intervals shown in Table 4-1.

In surficial sediment samples collected from Portage Creek downstream of Alcott Dam, PCB were detected in all but one of the 38 samples. PCB concentrations were less than 1.0 mg/kg in approximately 43% of the surficial sediment samples. In the subsurface Portage Creek sediment samples, 19% were reported as having PCB concentrations less than 1.0 mg/kg. None of the sediment samples collected from Portage Creek exceeded 100 mg/kg PCB.

> In general, higher sediment PCB concentrations are found in areas with:
>
> - lower water velocity
> - higher organic carbon content (TOC)
> - finer sediments (more silts and clays)

The nature and extent of PCB in sediment were evaluated with respect to vertical and horizontal spatial distribution, relationships between PCB and factors that are known to affect PCB distribution in sediment, and the spatial distribution of PCB mass in the sediment. Factors that can account for the variation of PCB concentration in Kalamazoo River sediments include: TOC concentration, particle size distribution (and, more qualitatively, texture), depth of sediment, water velocity, and distance from upstream sources. The following sections discuss the relationships between PCB and these parameters on a reach-by-reach basis, as well as for the river as a whole. Where appropriate, a linear regression model was applied to quantitatively determine the strength of the relationship. To reduce the effects of increasing frequency of non-detect values as sample depth increases, these relationships were evaluated using only surficial samples. In several cases, the use of the surficial samples yielded stronger statistical relationships despite the reduction in sample size. The results of these regressions can be found in Table 4-2.

After these factors were examined on an individual basis, a multivariate regression model was utilized to examine the combined variance of the independent factors on sediment PCB concentration. The results of the multivariate model also illustrate the amount of covariance between these factors based upon a comparison of the sum of squares error for each parameter to that of the whole model. The results of the multivariate regression analysis can be found in Table 4-2, and are discussed in subsection 4.3.1.6.

4.3.1.1 Spatial Distribution of PCB in Sediment

> ➢ Hydrologic characteristics play a key role in PCB distribution – low energy reaches such as the current impoundments have concentrated most of the fine-grained sediment and PCB.

The geographic distribution of PCB in the Kalamazoo River has been, and continues to be, affected by the hydrologic characteristics of the river. In general, PCB concentrations throughout the river as a whole were low; however, PCB tend to be more prevalent in the low energy depositional areas of the river associated with the current and former impounded areas.

The geographic distribution of reported PCB concentrations is shown on Figures 4-6 and 4-7 by river mile downstream from the Morrow Lake inlet (35th Street) and by sediment depth interval. The segment of the river between Morrow Dam and Main Street, Plainwell, is divided by the confluence with Portage Creek. Upstream of the Portage Creek confluence, the arithmetic surface area-weighted average concentration (SWAC)[1] for PCB was 0.90 mg/kg, which was largely influenced by one sample at transect KPT-20. This adjusted average is 74% lower (0.23 mg/kg) when the single highest reported concentration (86 mg/kg) is censored. The SWAC for PCB between Portage Creek and Main Street, Plainwell, was 0.87 mg/kg. Reported concentrations decreased with downstream distance in this reach, with the exception of a transect just upstream of 102nd Avenue (transect KPT-50) in Plainwell.

Reach	Surface Area Weighted Average PCB Concentration (mg/kg)
Morrow Lake (from MDNR data)	0.87
Marrow Dam to Portage Creek	0.90
Portage Creek to Main Street, Plainwell	0.87
Former Plainwell Impoundment	4.1
Otsego City Impoundment	4.8
Former Otsego Impoundment	3.2
Former Trowbridge Impoundment	3.0
Trowbridge Dam to Allegan City Line	0.43
Allegan City Impoundment	3.0
Lake Allegan	3.2

How good is the data set? Don't need more samples to get better SWAC estimate?

Downstream of Main Street, Plainwell, there are several former and current impoundments. The dams alter the flow dynamics of the river and affect the distribution of both sediment and PCB. A common characteristic of sediment from the former impoundments is the increased frequency of higher concentration PCB reported for samples collected near the dams. The former Plainwell, Otsego, and Trowbridge impoundments all displayed this trend. In addition,

[1] The SWAC was calculated as the sum of the arithmetic average PCB concentration multiplied by the surface area for each textural stratum (i.e., fine- or coarse-grained) divided by the sum of the surface area of each textural stratum within a reach.

the investigations revealed a generally increasing depth of PCB-containing sediment at transects immediately upstream of these dams. The SWACs for PCB in surface sediments for the former Plainwell, Otsego, and Trowbridge impoundments and the Otsego City Impoundment were 4.1 mg/kg, 3.2 mg/kg, 3.0 mg/kg, and 4.8 mg/kg, respectively. As indicated previously, the arithmetic average concentrations are fairly sensitive to relatively high, but infrequent, PCB concentrations, as is typical in log-normal distributions. As an extreme example, consider that the SWAC for PCB drops from 3.2 mg/kg to 0.29 mg/kg in the former Otsego Impoundment when the single highest reported PCB concentration (156 mg/kg) is removed from the average.

The variations in PCB across the channel were analyzed by comparing PCB results from cores collected closest to the bank to PCB concentrations from cores collected from the channel. Figure 4-8 shows the geometric mean and 95 percent confidence limits (about the mean) for sediments near the bank and in the channel on a dry-weight and TOC-adjusted basis. Except for in Lake Allegan, PCB concentrations in the channel were lower than PCB concentrations from the near-shore cores. Channel PCB concentrations were significantly lower ($p<0.05$) than near-shore PCB concentrations in the surface sediment between Portage Creek and Plainwell Dam, and between Trowbridge Dam and the Allegan City line (both of which are faster moving, free flowing sections of the river compared to existing impoundments). The difference between near-shore and mid-channel PCB concentrations reflect geomorphologic processes: more deposition in rivers would be expected near the banks, where the water is the slowest. Immediately behind Plainwell Dam the discrepancy is caused in part by slumping of the steep banks of PCB-containing former sediment into the river, which elevates the near-shore PCB concentration. In contrast, in the depositional environment of Lake Allegan, the near-shore PCB concentrations are lower in PCB than those within the main body of the lake. This would be expected in a lake environment, where the deepest part of the water column affords a longer settling time for fine grained material, while sediment near shore is subject to wave action and other disturbances. When dry-weight PCB concentrations are adjusted for TOC in the sediment, there are no consistent trends in or significant differences between near-shore and mid-channel PCB concentrations. The levels of PCB per unit of TOC in surface sediments are indicative of the relative availability of the PCB for exposure and accumulation in aquatic organisms (i.e., bioavailability). Thus, the TOC-adjusted PCB data indicate that from a bioavailability standpoint, the higher concentration in sediment near the shore are as bioavailable as those in the deeper areas.

The variability of PCB concentration in surface sediment on a small geographic scale was evaluated by a special geostatistical study (BBL, 1994e). The geostatistical analysis demonstrated a relatively high degree of variability in PCB concentration over relatively small distances; approximately half of the variability on PCB concentration was independent of spatial relationships, no matter how close the adjacent sample was collected. Results of the geostatistical pilot study showed that a longitudinal distance of 125 to 150 feet or less is required to establish statistical correlation between sediment samples. In the lateral dimension, it was determined that channel characteristics, such as location within a channel and position in straight channels or around river bends, strongly influence the observed PCB concentrations. These results confirm that geomorphological and hydrologic characteristics are better indicators of expected PCB concentration than inter-sample correlation (for example, along a gradient), which is virtually non-existent in the Kalamazoo River.

4.3.1.2 Relationships among Water Velocity, Particle Size, and PCB Concentration

PCB concentrations in Kalamazoo River sediment were generally inversely related to both water velocity and sediment particle size. As would be expected, the higher velocity areas tended to contain material with a larger particle size and a lower percentage of silt and clay (defined as material passing a #200 sieve).

> - 95% of sediment cores visually classified as coarse texture had PCB concentrations less than 1.0 mg/kg. Of these, 72% were less than 0.10 mg/kg and 48% were non-detect.
> - 69% of cores visually classified as fine texture had PCB concentrations greater than 0.10 mg/kg. 44% of fine texture cores had PCB concentrations greater than 1.0 mg/kg.

As can be seen in Table 4-2, statistically significant relationships ($p<0.05$) between water velocity and PCB concentration were present for surface sediment PCB and all sediment PCB concentrations between Morrow Dam and Main Street, Plainwell and in the former Trowbridge Impoundment. In addition, significant relationships ($p<0.05$) exist for all sediment depth data collected between the former Trowbridge Dam and the Allegan City Dam. Multiple velocity measurements were not made in Lake Allegan, but it is likely that a similar relationship between PCB and velocity would exist due to its depositional environment.

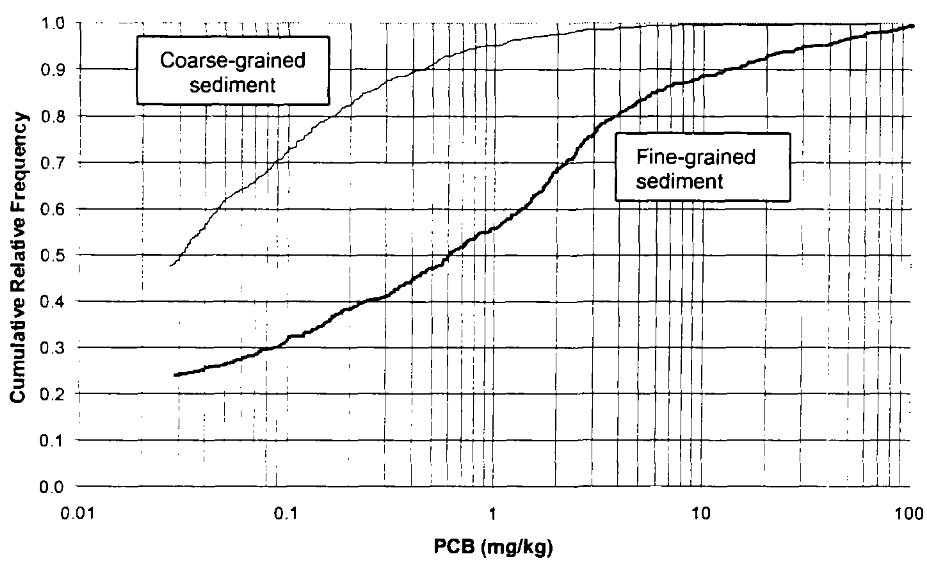
All collected sediment cores were classified as being fine or coarse in texture based on a visual rating system. This 1997 classification of cores[2] into fine and coarse texture classes effectively separated two distinct PCB concentration populations that can be used to define the expected relationships between PCB and percent solids, median particle size, percent silt and clay, and TOC. Each of these parameters is related to, and could be expected to predict, PCB

[2] Part of the stratified evaluation of the sediment core data included a sediment texture reclassification of frozen cores using more precise methodology than was used in 1994. The sediment investigation included particle-size distribution analysis of sediment samples from 616 cores collected from throughout the Kalamazoo River and Portage Creek. These grain-size distribution data were used to evaluate the sediment designations either as fine- or coarse-grained. Independent of both the previous classification and the analytical results, each core also was reclassified based on the physical description recorded in the field logs at the time of core collection, using a simple zero-to-five numeric rating system, where zero represents rock and gravel, 1 represents gravel with some sands, 2 represents medium to coarse sands, 3 represents fine sands with a trace of medium to coarse sands, 4 represents silts with fine sands, and 5 represents silts and organic matter. The results of the reclassification are provided in correspondence between BBL and MDEQ (Brown, 1997). Based on the particle-size data, cores rated 3 or less were reclassified as coarse and those greater than 3 were classified as fine. These classifications were later evaluated against PCB and TOC data and found to provide successful stratification of sediment cores. A sensitivity analysis of the reclassification is provided in correspondence between BBL and MDEQ (Brown, 1998). All references to fine and coarse sediment pertain to this reclassification.

populations; however, on a riverwide basis, there is enough variability in the relationships between these parameters and PCB concentrations that visual rating alone is as effective a predictor of PCB levels.

Riverwide, the two distinct PCB distributions in fine and coarse sediment are apparent in the upper 1 foot of sediment, as shown in the figure below. Samples deeper than 1 foot include more non-detections as a function of depth, and were not included in this evaluation. In the upper foot of sediment, approximately 95% of the cores classified as coarse by visual classification had PCB concentrations less than 1.0 mg/kg. Approximately 72% were less than 0.1 mg/kg, and PCB were not detected in approximately 48% of the coarse samples analyzed for PCB. Conversely, approximately 32% of the cores visually classified as fine had PCB concentrations less than 0.10 mg/kg, and 56% had PCB concentrations less than 1.0 mg/kg. Thus, the visual classification of cores effectively separates coarse cores (which generally contain less than 1.0 mg/kg) from fine cores (which generally exhibit a wider range of PCB concentrations).

Cumulative Relative PCB Frequency Distribution in the Upper One Foot of Kalamazoo River Sediment



The geometric mean PCB concentrations for sediments classified as fine and coarse are presented on Figure 4-9 by reach and by depth interval. This figure clearly indicates the separation of PCB concentrations between fine and coarse sediment. In about half the river reaches, the average PCB concentrations of coarse and fine-grained sediment samples are statistically different ($p<0.05$) at multiple depth intervals, and in many other cases the PCB distributions exhibit very little overlap with one another. Geometric average PCB concentrations in surface sediment were significantly different ($p<0.05$) between the fine and coarse classification in 6 out of the 9 river reaches between Morrow Dam and Lake Allegan Dam. In Portage Creek, no significant difference was observed between PCB in fine and coarse cores. Not surprisingly, this difference is smaller and less frequent as the sample depth increases and both populations include greater frequencies of nondetect results and fewer PCB values. Lake Allegan, which does not exhibit a statistical difference between PCB concentrations in fine and coarse sediment, was classified as having over 80% fine cores and a wide confidence interval around the geometric mean for coarse sediments caused by a small sample size (n = 4).

To quantitatively evaluate the PCB trends within the stratified populations, correlations between sample PCB concentration and percentage of silt and clay (measured as the percent of the sample passing a No. 200 sieve) were made. Typically, PCB concentration was more strongly correlated with the occurrence of silt and clay in the lower reaches of the river than in the free flowing upper reaches of the river; from the former Trowbridge Impoundment through Lake Allegan, the determinant of correlation (r^2) ranged from 0.19 to 0.54 ($p<0.001$; Table 4-2), while PCB concentration was not significantly correlated with percent silt and clay ($p<0.05$) between Portage Creek and Plainwell Dam between Portage Creek and Plainwell Dam.

The relative frequency of percent silt and clay in cores classified as fine and coarse is distinctly different between the upper and lower reaches of the river, as shown on Figure 4-10. Silts and clays comprise a greater fraction of fine sediments in the lower river reaches than in the upper river reaches. The percent silt and clay distribution was roughly the same throughout the river for coarse cores. However, in fine cores, the percent silt and clay upstream of the former Plainwell Impoundment was markedly different from the rest of the river; between Morrow Dam and Main Street, Plainwell, approximately 80% of the samples classified as fine had less than 30% silt and clay, whereas, in the rest of the river, only approximately 40% had less than 30% silt and clay and almost 20% of fine samples had greater than 90% silt and clay. This is indicative of the predominance of depositional environments downstream of Trowbridge Dam, where impounded water is slowed enough to deposit finer grains that are typically transported through the faster-moving upstream reaches. Similar trends were observed for PCB concentrations; in coarse cores, PCB concentrations were very similar throughout the river, but in fine cores, PCB concentrations were higher in the reaches downstream of Plainwell (most notably in Lake Allegan) given equivalent percent silts and clays.

> ➢ Slower-flowing reaches tend to accumulate fine-grained sediments; this creates a more favorable deposition environment for PCB.

Differences in the relationships between percent silt and clay and PCB among general river areas are apparent on Figure 4-11. These general areas include the upper, free-flowing portion of the river (Morrow Dam to Main Street, Plainwell), the former impoundments and Otsego City Impoundment, and the river downstream of Trowbridge Dam. General trends of higher PCB concentrations associated with higher percentages of silts and clays become stronger in the depositional downstream reaches. For the free-flowing section of the river between Morrow Dam and Main Street, Plainwell, both percent silt and clay and PCB concentrations are low and tend to plot closer to the origin. In the transitional reaches, which include the three former impoundments and Otsego City Impoundment, there was a wider range of percent silt and clay and PCB concentration and more scatter in the relationship between them. For sediments between the Trowbridge Dam and Lake Allegan Dam, PCB concentration and percent silt and clay were significantly correlated (r^2= 0.44, p<0.001). These trends showed that, among fine cores in the more depositional areas of the existing impoundments where sediment sorting facilitates the deposition of relatively uniform sediment, PCB are more likely to be associated with the occurrence of fine sediment than in other transitory portions of the river where the deposition of fine sediment is more variable, both spatially and temporally.

4.3.1.3 Relationship of PCB to Sediment Depth and Sample Depth

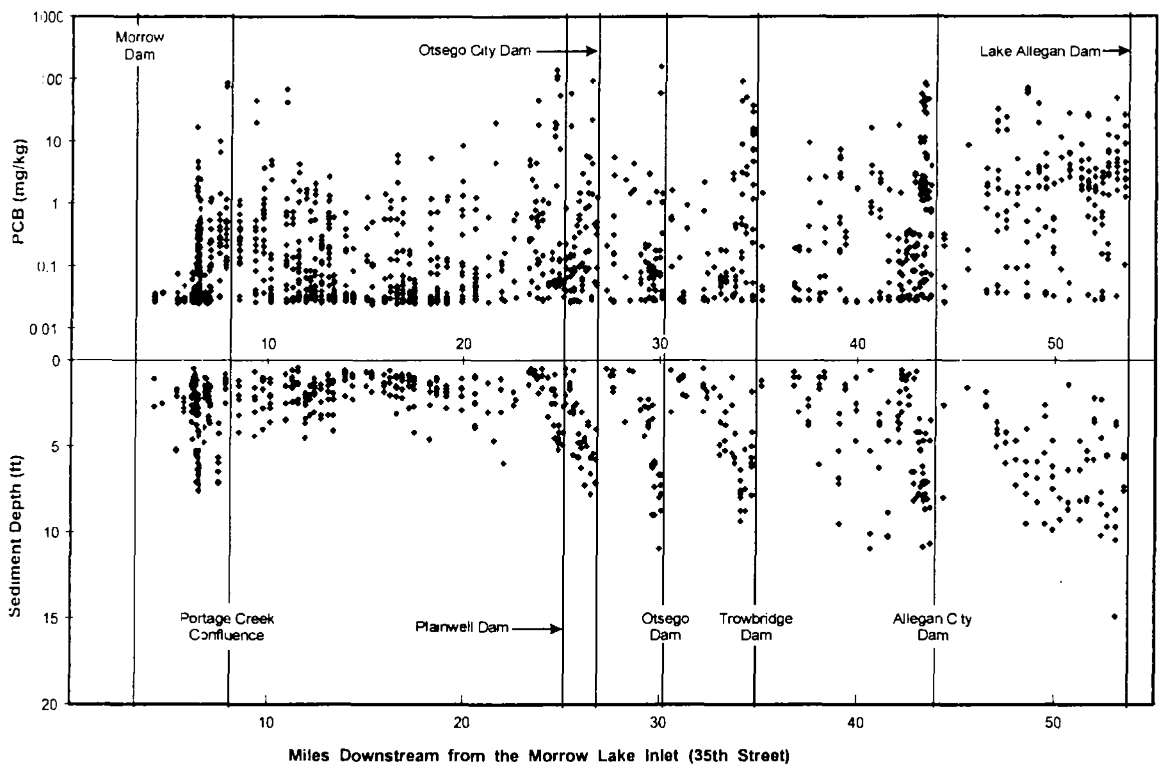
> ➢ Sediment depth ranges from a few inches to nearly 20 feet. The areas with deeper sediment tend to accumulate higher concentrations of PCB.

PCB concentrations were generally higher in areas of deeper sediment where long-term historical deposition has occurred. Sediment probing results show that overall sediment depth in the river ranges from inches in free-flowing areas to 20 feet at a probing location in Lake Allegan. The influence of existing and former dams on sediment deposition is evident in the figure below, which shows increased sediment thickness behind the dams. PCB concentrations show a similar trend: the areas with the deepest sediments tend to have the highest reported PCB concentrations.

PCB is most strongly correlated to sediment depth in the Kalamazoo River downstream of Trowbridge Dam. Regression statistics for PCB concentrations (surface only, as well as all depths) against sediment depth are provided in Table 4-2. Table 4-2 demonstrates that the highest, most statistically significant correlations occur in these downstream reaches, with the exception of the reach between Morrow Dam and Portage Creek. Geometric mean PCB concentrations for each sample depth interval are presented on Figure 4-12. These relationships indicate that, while PCB are generally associated with deeper sediment, sediment depth cannot be used as a reliable predictor of high PCB concentrations in most of the river.

Together, these data demonstrate two important points. First, remedial alternatives targeting removal of the highest PCB concentrations would by necessity target the deepest, highest-volume deposits of sediment. Second, throughout the historical downstream transport of PCB, the processes that govern natural attenuation have led to the accumulation and burial of a majority of the PCB in large deposits in the impoundments.

Sediment Probing Depth and PCB Concentration in Samples from the Upper One Foot of Sediment



Note:
Sediment depth shown is based upon probing depth for cores which were submitted for PCB analysis.

4.3.1.4 Relationship of PCB to Distance Downstream of Morrow Lake

PCB concentrations throughout the Kalamazoo River exhibited some correlation with distance downstream of Morrow Dam, as shown in Figures 4-6 and 4-7. Regression analysis showed a significant correlation (Table 4-2) between PCB in sediment and distance downstream of Morrow Dam in surface sediment in three reaches, Morrow Dam to Portage Creek, Former Trowbridge Impoundment, and Allegan City Impoundment (with r^2 values 0.14, 0.18, and 0.28, respectively). Unimpacted by dams, two of these reaches are predominantly faster flowing sections and contain a large proportion of coarse sediment. Including all surficial samples (from all reaches) a significant ($p<0.001$) correlation was observed with an r^2 of 0.17. Considering samples from all depth intervals, PCB was significantly correlated with distance downstream of Morrow Dam in 6 of the 9 reaches examined (r^2 values ranging from 0.013 to 0.17). A significant ($p<0.001$) relationship between PCB and distance from Morrow Dam (r^2 value of 0.13) was observed in the analysis of pooled samples from all reaches and all depth intervals. These results suggest that distance downstream does not significantly impact the PCB distribution (i.e., there is no downstream gradient

Aren't all these statistical correlations only as good as the data set?

with distance from historical KRSG sources) when compared to the effects of the various impoundments, which are depositional environments and tend to accumulate PCB.

4.3.1.5 Relationship of PCB to Total Organic Carbon

> ➤ The highest PCB concentrations are associated with high total organic carbon concentration.

PCB concentrations in Kalamazoo River sediment samples were strongly correlated with levels of TOC. Figure 4-13 illustrates relationships between PCB and TOC concentrations by river segment for fine and coarse sediment samples. This figure shows the relatively consistent trend throughout the river of the highest PCB concentrations being associated with high TOC concentrations and fine sediments, although high TOC concentrations did not necessarily indicate high PCB concentrations. The general relationship is expected because PCB tend to partition to organic material due to their hydrophobic nature. The relationship between PCB concentration and TOC concentration was strongest in the reaches of the river downstream of Trowbridge Dam, where historical deposition of PCB was the greatest.

For surficial sediment samples, regressions of TOC and PCB concentrations from all nine reaches were statistically significant ($p<0.05$) with r^2 values ranging from 0.025 between Portage Creek and Main Street, Plainwell, to 0.60 between the Trowbridge Dam and the Allegan City Line. For all reaches combined, surficial PCB concentrations were also significantly related to TOC concentrations (r^2 value 0.36, $p<0.001$). As evident from inspection of the regression statistics presented in Table 4-2, the correlations between PCB and TOC were stronger in surface sediments than for the pooled data from all core depth intervals. Age of sediment strata is one obvious source of variability to the relationships within the data pooled for all core intervals. Given the chronology of PCB release to the environment, it is expected that core sections representing pre-1950s sediment would have non-detectable PCB levels even though they may have high levels of TOC and silts and clays.

Based on regression analyses of PCB and TOC concentrations in all depths, significant correlation coefficients (r^2) ranged from 0.054 for sediment from the former Otsego Impoundment to 0.42 for sediment samples from between Trowbridge Dam and the Allegan City Line. Results of regression analyses are summarized in Table 4-2. Correlation coefficients for PCB and TOC concentrations for samples from all depths were statistically significant ($p<0.05$) for 8 out of the 9 reaches. TOC was not significantly related to PCB in the former Plainwell Impoundment.

4.3.1.6 Multivariate Regression Analysis

> ➢ TOC content and particle size are the variables that most significantly affect PCB distribution in sediment.

Results of the multivariate analyses of the parameters affecting the distribution of PCB in Kalamazoo River sediments show that TOC content and particle size are the main factors affecting the variations in sediment PCB concentrations. Multivariate analysis accounts for the covariance of independent variables in the determination of PCB concentration. In other words, individual correlations with PCB may be affected by correlations among the independent variables, such as high TOC being associated with higher silt and clay content. By comparing the r^2 of individual parameters to the r^2 of the regression of all parameters, a relative contribution of the individual parameters can be derived. The results of multivariate analytical modeling by river reach are provided in Table 4-2 and summarized in the table below.

TOC content made a statistically significant contribution to the overall multivariate model more frequently than any other parameter in both surficial samples and samples from all depths. TOC contributed a significant portion of the variability in PCB throughout the River. Interestingly, in the Allegan City Impoundment and Lake Allegan, TOC did not contribute significantly to PCB concentrations when other factors were accounted for. Percent silt and clay was second in frequency as the most significant factor in the model. The contribution of percent silt and clay to the overall explanation of variation in PCB concentrations was strongest in the Allegan City Impoundment and Lake Allegan. For these two reaches of the river, variations in particle size explained 57% and 28%, respectively, of the total amount of variation in PCB concentrations. These results show that the occurrence of PCB in the impoundments is a depositional phenomenon because PCB in these areas is more attributable to the settling of fine-grained material than to the organic content of the sediment.

Reach	n	p	Percent of PCB Variability Explained by the Model	Percent Contribution to PCB Variability Explained by the Model			
				TOC	Distance	Particle Size	Sediment Depth
Surface Samples Only							
Morrow Lake	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Morrow Dam to Portage Creek	89	< 0.001	43	12	11	7.3	21
Portage Creek to Main Street, Plainwell	74	< 0.001	30	75	NS	NS	NS
Former Plainwell Impoundment	36	0.012	29	91	NS	--	NS
Otsego City Impoundment	36	0.001	40	50	NS	--	NS
Former Otsego Impoundment	36	0.001	40	82	NS	--	NS
Former Trowbridge Impoundment	46	< 0.001	44	33	NS	--	31
Trowbridge Dam to Allegan City Line	47	< 0.001	61	75	NS	--	NS
Allegan City Impoundment	13	0.001	87	NS	NS	57	NS
Lake Allegan	32	< 0.004	42	NS	NS	28	NS
All Reaches	218	< 0.001	55	5.5	2.4	6.6	4.0
All Samples							
Morrow Lake	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Morrow Dam to Portage Creek	233	< 0.001	38	16	29	2.9	16
Portage Creek to Main Street, Plainwell	130	< 0.001	16	83	NS	NS	NS
Former Plainwell Impoundment	19	0.46	21	NS	NS	NS	NS
Otsego City Impoundment	19	0.077	43	76	NS	NS	NS
Former Otsego Impoundment	18	0.24	33	NS	NS	NS	NS
Former Trowbridge Impoundment	41	< 0.001	64	23	NS	NS	18
Trowbridge Dam to Allegan City Line	18	0.10	43	NS	NS	NS	NS
Allegan City Impoundment	54	< 0.001	46	NS	NS	51	NS
Lake Allegan	93	< 0.001	38	NS	NS	74	NS
All Reaches	625	< 0.001	36	12	0.3	11	4.5

Notes:
NS indicates that no statistical relationship exists at a level of $p<0.05$.
n indicates the sample size used in the regression analysis.
p indicates the significance level of the regression.
-- indicates that parameter was not included in the regression analysis due to small sample size.
TBD - to be determined upon receipt of 2000 data (see *Supplement to the Kalamazoo River RI/FS* [BBL, 2000e]).
Surficial depth interval typically was 0- to 2-inches, but did include some samples from 0- to 6-inches as well.

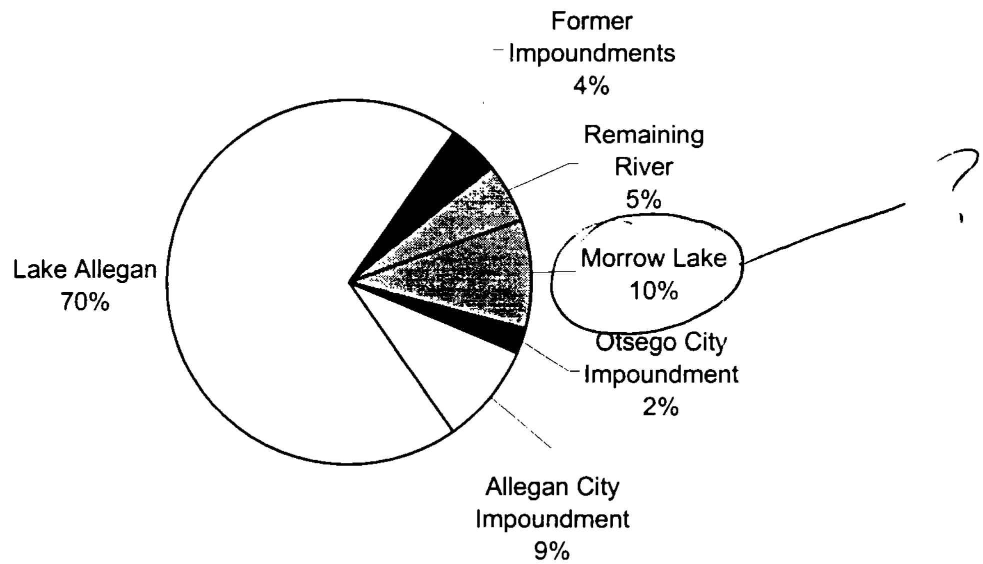
Model regressions for surficial sediments were statistically significant for all reaches and for the river as a whole. Regression r^2 values for individual reaches ranged from 0.29 ($p=0.012$) in the former Plainwell Impoundment, to 0.87 ($p=0.001$) in the Allegan City Impoundment. For the whole river surface sediments, the model yielded an r^2 value of 0.55 ($p<0.001$) based on a sample size of 218. Multivariate regression for sediment from all depths were significant for only 5 of the 9 reaches examined. Regression r^2 values for these reaches ranged from 0.16 for the reach between Portage Creek and Main Street, Plainwell, to 0.64 for sediments from the former Trowbridge Impoundment. The multivariate model for sediments from all depth intervals in the whole river was statistically significant ($p<0.001$)

and yielded an r^2 value of 0.36. Differences between surficial sediments and all sediment can be attributed to the higher frequency of nondetect PCB concentrations in deeper sediments that may have been deposited prior to the introduction of PCB to the river. The overall models show strong predictive capabilities for identifying areas most likely to have accumulations of PCB in the sediment.

4.3.1.7 PCB-Containing Sediment Volume and PCB Mass in Kalamazoo River Sediment

PCB concentrations were spatially integrated within the sediment volume to estimate PCB mass within the different reaches of the river. Using the texture descriptions and the depth of PCB detected in the corresponding cores, the volume of PCB-containing sediment was estimated for each river reach and each texture classification. Within each reach, the average arithmetic PCB concentration of each depth increment was used in conjunction with an estimate of the dry sediment mass per unit of in-situ volume (from the average percent solids concentration) to estimate an approximate PCB mass associated with each depth layer. The PCB mass in fine and coarse sediment was summed for each reach. A description of the river sediment volume and PCB mass calculations are provided in Appendix B.

Distribution of PCB Mass in Kalamazoo River Channel Sediment



Most of the PCB mass currently found in Kalamazoo River submerged sediment resides in Lake Allegan (see figure above). The distribution of sediment volumes and related PCB mass in the Kalamazoo River sediments is presented in Table 4-3. Approximately 29,300 kg of PCB reside in approximately 9,500,000 cy of current river sediments between the inlet to Morrow Lake and Lake Allegan Dam. Of the PCB mass in the current sediments, 10% are found in Morrow Lake sediment (upstream of the NPL Site), 9% are found in the Allegan City Impoundment, 4% are found in the current sediment of the former impoundments, and 7% are distributed throughout the rest of the river. In addition to the current channel sediment, there are an estimated 24,500 kg of PCB in 2,800,000 cy of exposed sediments in the three former impoundments. Thus, the current submerged sediments comprise 54% of the estimated total PCB mass (Figure 4-14), while the exposed sediment of the former impoundments contain the other 46% of the total amount of PCB in the system. Most PCB are deposited in impounded areas (former and existing). The estimated mass of PCB in exposed sediment is comparable to estimates of PCB eroded when the dams were removed (as calculated in Appendix F).

4.3.2 Other Constituents in Sediment

> ➢ Sediment samples were also analyzed for VOCs, SVOCs, pesticides, and metals.

Nine cores from the Kalamazoo River and Portage Creek were analyzed for TCL/TAL constituents. One fine-grained core from Portage Creek and from each major section of the Kalamazoo River, with the exception of Morrow Lake, were analyzed. A list of sampling locations for all analyses is provided in Appendix C. All sample intervals from individual cores that were analyzed for PCB were also analyzed for TCL/TAL constituents, including VOCs, SVOCs, pesticides, and metals.

A summary of the detected VOCs is presented in Appendix C. Methylene chloride and trichloroethene (TCE) were detected in the 0- to 2-inch sampling interval at most locations. Concentrations in this interval for methylene chloride ranged from not detected to 55 mg/kg, while TCE ranged from not detected to 140 mg/kg. Elevated concentrations for these two constituents were reported for the core from KPT122-2 between Trowbridge Dam and the Allegan City line. Transect PPT5-2, located in Portage Creek, had the highest number of VOC detections throughout an individual core.

The most frequently detected SVOCs in sediment samples were benzo(a)anthracene, benzo(b)fluoranthene, chrysene, bis(2-ethylhexyl)phthalate, fluoranthene, 4-methylphenol, phenanthrene, and pyrene; none of which are typically found in residuals. Bis(2-ethylhexyl)phthalate was the highest reported SVOC concentration; a concentration of 18 mg/kg was reported for the 0- to 2-inch depth interval from transect KPT 157-1. Transect PPT 5-2, located in Portage Creek, had the greatest frequency of SVOC detections throughout an individual core, and also had the highest reported concentrations of fluoranthene (13 mg/kg), phenanthrene (13 mg/kg), and pyrene (14 mg/kg), all from the 2- to 12-inch sampling interval. A summary of the detected SVOCs is presented in Appendix C.

The primary pesticides detected in sediment samples were gamma-chlordane, 4,4'-DDD, 4,4'-DDT, and endrin aldehyde. Pesticides were detected in the 0- to 2-inch interval of all the cores collected, except for the former Plainwell Impoundment, the former Otsego Impoundment, and the former Trowbridge Impoundment (cores from KPT65-3, KPT92-7, and KPT104-1, respectively). Pesticides were not detected at any depth in the core from the former Plainwell Impoundment, and were only detected at depths greater than 2.4 feet in the former Otsego Impoundment core. The only detection of pesticide in the former Trowbridge Impoundment was methoxychlor (0.015 mg/kg) in the 1- to 1.5-foot interval of the core. Transect PPT 5-2, located in Portage Creek, exhibited the largest variety of pesticide detections throughout the core. A summary of the detected pesticide results is presented in Appendix C.

TAL constituents were detected at various concentrations in the majority of samples. This was expected, since TAL constituents naturally occur in soil and sediment. Elevated surface concentrations (0- to 2-inch interval) of lead and mercury occurred at transects KPT 65-3 and KPT 104-1 located between Main Street, Plainwell, and the Plainwell Dam, and between the Otsego Dam and the Trowbridge Dam, respectively. Transect KPT 104-1 had the highest surficial sediment lead concentration (930 mg/kg) and the highest surficial mercury concentration (2.4 mg/kg). A summary of the detected TAL results is presented in Appendix C.

4.4 Focused Soil and Sediment Sampling

From April through August 2000, soil and sediment cores from 115 locations were collected from the Kalamazoo River and floodplain areas as part of the Focused Sampling Program designed by the MDEQ. The sample locations were specifically selected by the MDEQ to characterize or further characterize known and suspected PCB point sources and historic waste disposal areas, areas of suspected fine-grained sediment deposition within the Kalamazoo River, floodplain soils, and exposed sediments. Selection of sample locations favored areas likely to have higher PCB concentrations in contrast to cores collected during the 1993 and 1994 investigations, which were positioned without regard to expected result. Thus, it was expected that the 2000 focused samples would yield higher PCB concentrations than the earlier data. Core locations and PCB concentrations for all cores are shown on Figures 4-15, 4-16, and 4-17.

Upon review of the location descriptions provided by the MDEQ (von Gunten, 2000) and field notes documenting the collection activities, the 115 focused soil and sediment core locations were divided into the following types:

1) Focused soil sampling of former impoundment exposed sediment (14 cores);

2) Focused soil sampling of the Kalamazoo River Floodplain (34 cores);
3) Focused sediment sampling of Kalamazoo River Sediment (39 cores);
4) Focused soil sampling of islands within the Kalamazoo River (10 cores);
5) Focused sediment sampling of known or suspected point sources or waste disposal areas (8 cores); and
6) Focused soil sampling within the Otsego City Impoundment (10 cores).

This classification of the soil and sediment cores collected as part of the Focused Sampling Program allows for the comparison of the results to the results of previous investigations (i.e., Sediment Characterization, Floodplain Soils, and Former Impoundment Sediment Investigations). Physical and analytical data for each of these categories are summarized for comparison in Table 4-4, which shows distinct separation of characteristics between the groups of samples based on their locations. Figure 4-18 shows the relationship between PCB and TOC for surficial samples for each of the six categories. Data collected during the focused sampling effort are presented in Appendix E.

4.4.1 Focused Sampling of Exposed Sediments

This section presents the results of the focused sampling of former impoundment exposed sediments and compares the results to those of the Former Impoundment Sediment Investigation. The results of PCB analyses for focused soil samples collected within the boundaries of the former impoundment areas are presented on Figures 4-16 and 4-17, and summarized in Table 4-4.

A total of 14 cores were collected from the former Plainwell (1 core), Otsego (5 cores), and Trowbridge (8 cores) impoundments, which yielded 52 samples for physical characterization and PCB analyses. The physical characterization of the cores collected within the boundaries of the former impoundments was generally consistent with the findings of the 1994 Former Impoundment Sediment Investigation (Figure 4-19). Total solids from the focused cores ranged between 22% and 85%, with an arithmetic mean value of 55%, compared to a mean of 53% (range of 12 to 94%) in 1994. The percent silt and clay measured in the exposed sediment cores collected from the former impoundments averaged 66%, ranging from 6.4% to 98%. TOC ranged from 0.1% to 38.6% (average of 8.4%) in 1994 former impoundment samples, while TOC results for focused samples ranged between 0.14% to 15%, averaging 6.9%. Based on the results of the t-test conducted on the focused and 1994 data, it was determined that both TOC and percent solids were not significantly different ($t_{calculated} < t_{critical}$) at 95% confidence. The results of the physical characterization of the focused exposed sediment samples collected from the impoundments are summarized in Table 4-4.

Total PCB concentrations measured in the exposed sediment samples collected from the former impoundments ranged from non-detect to 130 mg/kg with an average of 13 mg/kg (geometric mean of 1.6 mg/kg). Total PCB concentrations were reported as not detected in 23% of samples collected within the boundaries of the former impoundments, while 23% of detectable PCB concentrations were less than or equal to 1 mg/kg. Higher levels of PCB generally were observed within sub-surface samples (i.e., greater than 6-inches bgs). 31% of exposed sediment samples contained PCB concentrations greater than 10 mg/kg, with 63% of these samples collected at depths greater than 6-inches. The maximum detected PCB concentration (130 mg/kg) was observed in a sample collected from the 18- to 24-inch depth interval in the former Trowbridge Impoundment.

Measured PCB concentrations in samples collected within each of the former impoundments are consistent with data collected during the 1994 exposed sediment investigation. Results of t-tests conducted on data from the former Trowbridge and Otsego impoundments indicate that the observed PCB concentrations in the focused data are not statistically different than the respective 1994 results of exposed sediment sampling ($p < 0.05$). (A t-test could not be conducted for the former Plainwell Impoundment since only one core was collected within the impoundment boundaries during the focused sampling.)

4.4.2 Focused Sampling of the Kalamazoo River Floodplain

The MDEQ-specified focused sampling included the collection of 33 cores from the Kalamazoo River floodplain. Of the 34 floodplain cores, 27 were characterized as soil, with the remaining 7 characterized as sediment. The seven cores characterized as sediment (FF-17, FF-33, FF-34, FF-83, FF-85, FF-92, and FF-104) were collected within free-standing water and potential depositional areas in the Kalamazoo River floodplain, outside of the main river channel. It is likely that some of those areas are dry for a significant portion of the year. Therefore, based on their location, it was assumed that these samples would be best analyzed as floodplain samples. From all 34 cores, 114 samples were analyzed for PCB, TOC, and physical properties. This section presents the results of focused sampling of the Kalamazoo River floodplain and, where pertinent, the focused floodplain results are compared to the results obtained from the 1993 floodplain investigation. Results of the PCB analysis are provided on Figures 4-15, 4-16, and 4-17, and summarized in Table 4-4.

Percent total solids in focused floodplain cores ranged from 15% to 94%, averaging 63%. Percent silt and clay averaged 43%, ranging between 0.30% and 94%. TOC content in focused floodplain soils ranged from 0.072% to 28%, averaging 4.6%.

PCB concentrations in focused floodplain samples ranged from not detected to 20 mg/kg, averaging 1.0 mg/kg (geometric mean of 0.15 mg/kg). More than half of all samples (60 of 114, or 53%) had non-detectable concentrations of PCB. Of the 54 samples with detectable concentrations of PCB, 57% were less than 1 mg/kg. In surface floodplain samples, PCB concentrations in 32 of 34 samples (94%) were less than 4 mg/kg. The two samples which had reported PCB concentrations above 4 mg/kg (FF-37 and FF-48) were collected upstream of Plainwell. Although these samples were located within the Kalamazoo River floodplain, physical data for these samples show that the soil samples were high in silt and clay and TOC, and were not indicative of the native sandy soils typical of the Kalamazoo River floodplain. The high water content, and corresponding low percent solids in these two samples (47% and 34%), high percent silt and clay (71% and 93%), and high percent TOC (10% and 11%) indicate that these samples are more indicative of sediment than floodplain soils.

4.4.3 Focused Sampling of Kalamazoo River Sediment

Thirty-nine of the focused core sampling locations were within the Kalamazoo River channel. These cores produced 164 sediment samples for analyses. The physical data reported for the focused sediment samples are very similar to the physical data reported for fine sediments collected during the 1993/1994 sediment investigation. Percent solids content in the channel sediment samples collected as part of the Focused Sampling program ranged between 12% and 93%, with an average of 54%. Percent silt and clay ranged between 1.3% to 100%, with an average value of 52%. TOC content ranged between 0.056% and 42% with an arithmetic mean value of 6.1%. The results of the physical characterization of the focused channel sediment samples are summarized in Table 4-4.

In comparison to the focused data summarized above, percent solids content of 1993/1994 fine sediments ranged between 16% and 99.7%, averaging 64%; silt and clay in 1993/1994 fine sediments averaged 38% (range of 0.9% and 99.2%), and TOC in 1993/1994 fine sediment cores ranged between not detected and 46%, with an average value of 5.0%. Based on the results of t-tests comparing TOC, percent solids, and percent silt and clay data collected in 2000 to the corresponding data 1993/1994 data, the focused sediment and 1993 fine sediment physical data are not significantly different.

The relative cumulative frequency distributions for TOC, percent solids, and percent silt and clay in focused sediment samples are presented on Figures 4-20, 4-21, and 4-22, respectively, along with the results from the 1993/1994 sediment investigation. These figures illustrate that, even though not statistically significant, the physical characteristics of the 2000 focused cores as a whole are slightly finer than the fine cores collected in 1993 and 1994, especially downstream of Main Street, Plainwell.

> ➢ The bias toward finer-grained sediments in the Focused Sampling Program limits the direct comparison of these data to the 1993/1994 sediment data.

PCB concentrations in the focused sediment samples ranged from not detected to 120 mg/kg (in the 24- to 36-inch depth interval at core location FF-80), with an average PCB concentration of 6.9 mg/kg (geometric mean of 0.96 mg/kg). Forty-six percent of channel sediment samples analyzed for PCB resulted in concentrations less than 1.0 mg/kg, with only 17% of all samples (28 of 164) returning PCB concentrations greater than 10 mg/kg. Of those samples with PCB concentrations greater than 10 mg/kg, 86% (24 of 28) were found at depths greater than 6-inches bgs. The arithmetic average surficial (0- to 2-inch bgs) PCB concentrations in focused sediment samples was 2.2 mg/kg (geometric mean of 0.77 mg/kg), while average PCB concentrations in the 2- to 6-inch, 6- to 12-inch, and 12- to 24-inch depth intervals were 3.6 mg/kg, 9.2 mg/kg, and 9.9 mg/kg (geometric means of 1.0 mg/kg, 1.7 mg/kg, and 0.80 mg/kg, respectively). A summary of the results of the PCB analysis of the focused sediment samples is presented in Table 4-4. Results of the PCB analysis are presented on Figures 4-15, 4-16, and 4-17.

As a whole, PCB data from the focused sediment cores are well within the range observed in the 1993/1994 cores. However, the focused selection of the core locations limits the comparability of this data to the samples collected in 1993/1994 which were located independently of expected sediment texture. PCB concentrations in fine sediment cores collected during the 1993/1994 sediment investigation ranged from non-detected to 160 mg/kg, averaging 4.0 mg/kg. Results of a t-test of all the focused sediment PCB results and PCB data reported for all 1993 fine sediment cores showed no significant difference between PCB concentrations in the two data sets.

To further compare focused sediment data to 1993/1994 sediment data, regression analyses were performed on a reach-by-reach basis. Results of regression analyses performed on the 1993 sediment investigation data revealed statistically significant relationships between PCB and both TOC and percent silt and clay (see Section 4.3.1.6). However, similar relationships were not observed consistently in focused sampling data. At focused sampling locations within the reaches from Morrow Dam to Portage Creek, and Portage Creek to Main Street, Plainwell, statistically significant relationships ($p < 0.05$) were observed between surficial PCB and TOC concentrations in both reaches, and between surficial PCB and percent silt and clay between Portage Creek and Main Street, Plainwell. However, no statistically significant relationship was observed between surficial sediment PCB and TOC, or surficial sediment PCB and percent silt and clay, downstream of Main Street, Plainwell.

Surface samples collected from Lake Allegan suggest a decline of TOC-adjusted PCB concentrations between 1994 and 2000. TOC-adjusted PCB data from the RI transects which overlap geographically with the focused sediment cores were compared to the surface TOC-adjusted PCB results from 2000. To allow for a more meaningful evaluation of differences over time, data were restricted to comparable sediment characteristics and depositional environments. The MDEQ-directed focused samples were primarily located in cove areas, and exhibited greater amounts of finer grains and higher TOC than samples collected in 1993 and 1994. To directly compare results between surveys, data were stratified by geographic area and TOC so that only surface samples from similar areas of Lake Allegan with TOC greater than 6% were used. These data include 68% (26 of 38) of the RI surface samples that were collected from the same area as the focused samples and 90% (9 of 10) of the focused surface samples. The 2000 samples have a lower arithmetic average concentration (51 mg/kg) than was observed in the data collected in 1994 (68 mg/kg).

4.4.4 Focused Sampling of Islands within the Kalamazoo River

This section presents the physical and analytical data results of the focused sampling of islands within the Kalamazoo River. Ten of the 115 focused sampling cores were collected from islands within the Kalamazoo River. The 10 cores produced 30 samples for PCB, TOC, and physical character analysis. These island soil samples would not be representative of the typical floodplain soils due to their decreased accessibility for human contact; therefore the results and analysis are presented separately. Physical and analytical data results are summarized in Table 4-4 and PCB results presented on Figures 4-15, 4-16, and 4-17.

Percent solids in focused island cores ranged from 47% to 88% and averaged 67%. Percent silt and clay ranged between 4.3% and 79%, averaging 36%. TOC in island soil samples averaged 4.2%, ranging from not detected to 14%. PCB concentrations measured on these samples ranged from not detected to 15 mg/kg, and averaged 2.2 mg/kg (geometric mean of 0.40 mg/kg). Non-detectable concentrations of PCB were reported in 48% of samples collected from the Kalamazoo River islands, while 30% of detected PCB concentration were below 1 mg/kg.

4.4.5 Focused Sampling at Known or Suspected Point Sources or Waste Disposal Areas

Eight cores were specified by the MDEQ at or near locations of industrial or municipal facilities, outfalls, or suspected former industrial dumping areas. Three of the eight cores were characterized as soil and were collected from "suspected former dumping area(s)" (von Gunten, 2000) associated with the former Hawthorne Mill in Kalamazoo. The remaining five cores were taken from sediments within the river, including two from near the Fort James Outfall, two near the Parchment WWTP outfall, and one in the vicinity of the Kalamazoo Water Reclamation Plant (WRP) outfall. Results of the individual samples are presented in the table below. PCB results are presented on Figure 4-15.

PCB Results from Near Outfalls

Focused Core Location Depth Interval	Number of Cores	Number of Samples	Physical Data: Solids (%) Range[1]	Solids (%) Arithmetic Mean	Silt and Clay (%) Range	Silt and Clay (%) Arithmetic Mean	Analytical Data: Total Organic Carbon (%) Range	Total Organic Carbon (%) Arithmetic Mean	PCB Concentration (mg/kg) Range	PCB Concentration (mg/kg) Arithmetic Mean	PCB Concentration (mg/kg) Geometric Mean
Former Fort James Outfall											
Surface (0- to 2-inch)	2	2	77 - 78	78	3.2 - 5.7	4.5	1.7 - 2.1	1.9	0.18 - 0.60	0.39	0.32
All Depths (0- to 24-inch)		8	52 - 86	74	3.2 - 79	18	0.14 - 12	2.8	0.18 - 27	5.2	1.5
Kalamazoo River WRP											
Surface (0- to 2-inch)	1	1	54	NA	37	NA	1.0	NA	0.23	NA	NA
All Depths (0- to 24-inch)		4	54 - 94	81	4.4 - 37	13	0.50 - 1.4	0.91	0.044 - 0.23	0.12	0.10
Former Parchment WWTP											
Surface (0- to 2-inch)	1	1	20	NA	63	NA	25	NA	0.39	NA	NA
All Depths (0- to 24-inch)		4	20 - 71	41	48 - 63	54	8.3 - 25	16	0.37 - 0.73	0.5	0.47
Downstream of Parchment Outfall											
Surface (0- to 2-inch)	1	1	71	NA	11	NA	0.49	NA	0.072	NA	NA
All Depths (0- to 24-inch)		4	71 - 81	77	4.5 - 11	7.8	0.15 - 2.5	0.86	0.072 - 0.52	0.22	0.16
F Former Hawthorne Mill											
Surface (0- to 6-inch)	3	3	50 - 58	54	91 - 94	92	6.9 - 8.2	7.4	0.15 - 0.93	0.45	0.33
All Depths (0- to 24-inch)		10	50 - 77	64	13 - 94	64	1 - 16	6.3	ND - 220	23	0.18

Notes:
If only one sample was collected, than the value is presented.
NA - Not applicable, due to sample size.

4.4.6 Focused Sampling within the Otsego City Impoundment

Ten of the focused sampling locations were located within soils of the Otsego City Impoundment. Eight of the ten cores from the Otsego City Impoundment were collected from elevations less than the historical pool elevation (699 ft; USGS, 1973), therefore these samples would not be considered typical floodplain soil samples. In addition, review of the physical data from these cores shows that they are very similar to the exposed sediments collected within the former impoundment areas and are not typical of the native sandy soil found in floodplain soils. Results of the PCB analysis are presented on Figure 4-16 and summarized in Table 4-4.

Percent solids in soil samples collected from the Otsego City Impoundment ranged from 13% to 92% and averaged 48%. Percent silt and clay in these samples averaged 51%, ranging between 2.0% and 99%. TOC in focused samples collected from the Otsego City Impoundment ranged between 0.16% and 45%, with an average value of 14%. Based on these results alone, it is apparent that very fine, highly organic soils were targeted within the Otsego City Impoundment. In the surface soil (0- to 6-inch depth), percent solids, silt and clay, and TOC averaged 43%, 67%, and 15%, respectively. These physical characteristics are statistically different (at 95% confidence) than the focused floodplain soil results, based on the results of the t-test analysis. Conversely, the percent solids, percent silt and clay, and TOC data from the Otsego City Impoundment soils were determined to be statically similar to the characteristics of exposed sediment from the former impoundments. Based on the physical data and results of the statistical analysis, it is apparent that the soil cores collected from the Otsego City Impoundment are more representative of former impoundment exposed sediment, and should not be considered typical floodplain soils.

Results of PCB analysis of the focused soil cores collected from the Otsego City Impoundment showed PCB concentrations ranging between not detected to 33 mg/kg, averaging 2.0 mg/kg (geometric mean of 0.19 mg/kg). PCB concentrations were reported as non-detect in 59% of samples collected in the Otsego City Impoundment, with 57% of detected PCB concentrations less than 1 mg/kg.

4.5 Surface Water

The following section presents a summary and findings of the surface water investigation, including a comparison of the results to earlier investigations and the results of ongoing monitoring. The RI surface water investigation is described in Section 2.5. General conclusions drawn from surface water investigations completed to date include:

- PCB were detected at locations upstream of the NPL Site in both the Kalamazoo River and Portage Creek, indicating PCB loading from upstream sources unrelated to the KRSG paper mills;
- Within the Site, PCB were not detected in 74% of the surface water samples collected in 1994;
- PCB concentrations in surface water have decreased significantly since the mid-1980s compared to data collected in 1994 and 1999; and
- Overall concentrations and loads of PCB appear to increase in a downstream direction between D Avenue and Plainwell and remain relatively constant throughout the remainder of the Site.

Surface water data used in the following analyses included:

- Data collected at various locations by the MDEQ (then MDNR) in 1985-1988;
- 1994 data collected during the RI surface water investigation;
- 1994/1995 data collected by the USEPA and USGS as part of the LMMBS; and
- 1999/2000 data collected by CDM on behalf of the MDEQ.

The number of PCB observations in surface water and the corresponding sampling locations are summarized by year below:

Location	River Mile	Year and Number of Sampling Events							
		1985	**1986**	**1987**	**1988**	**1994**	**1995**	**1999**	**2000**
Ceresco Dam	-6.7							3	
35th Street	0.0								
Morrow Dam	3.3							3	
River Street (SWK-1)	4.5	8	9	2	2	32		3	1
Sprinkle Road	5.4								1
King Highway	6.7		5					3	1
Kalamazoo Avenue	8.1							3	1
Michigan Avenue (SWK-2)	8.1	3	7	1		32			
Gull Street	8.5								1
Paterson Street	8.8	2	8	1					
Mosel Avenue	9.8		3	3					1
Pitcher Street	11.3								1
D Avenue (SWK-3)	14.7		1	3		10		3	
10th Street, Plainwell	23.3	4	2	3					
US 131, Plainwell	24.9							3	
Plainwell Dam	25.1	4	1					3	
Farmer Street (SWK-4)	27.0	4				32		3	
Otsego Dam	30.2	4						3	
26th Street	35.0	5						3	
Williams Road	39.4	4							
Allegan City Dam	43.6							3	
M-222 (SWK-5)	45.6	11	1			31			
Lake Allegan	54.7							3	
M-89 (SWK-6)	57.8					17		3	
New Richmond	68.9							3	
Douglas	76.2					22	16	2	

Note: The mid-1980s data were collected pursuant to an RI/FS of the Kalamazoo River under Michigan's Superfund program (then Act 307). The related analytical QA information is not available.

Data collected by the MDEQ (then MDNR) in the mid to late 1980s provide a historical data set against which more recent data can be compared to evaluate trends. Surface water data were collected by the MDEQ at various locations along the Kalamazoo River from 1985 to 1988; these data are presented and discussed in the MDNR-approved DCS report (BBEPC, 1992).

The surface water PCB data collected as part of the RI are presented in detail in *Draft Technical Memorandum 16* (BBL, 1995a), including annual PCB load estimates, comparison of RI data to historical data, and the evaluation of the relationship between PCB concentration and flow at various locations.

Surface water data from the LMMBS are presented in Appendix J. The LMMBS was conducted by the USEPA and the USGS to evaluate the flux of several constituents, including PCB, into and out of Lake Michigan. Among the tributary sampling locations surrounding Lake Michigan, the Kalamazoo River was sampled just downstream of the mouth of the Rabbit River between April 1994 and October 1995. The particulate and dissolved fractions of each surface water sample were analyzed for PCB congeners, TSS, and pesticides. Forty-two samples were collected during 38 sampling events. Tabular results of these analyses were provided by the USEPA in the fall of 1999 (Warren, 1999) in response to FOIA requests. Corresponding TSS concentrations were obtained from the USGS annual water report (Blumer, et al., 1996).

More recently, in the fall of 1999, the MDEQ performed surface water sampling along the Kalamazoo River. Samples were collected from 20 locations on the Kalamazoo River, and four locations on Portage Creek; the results of three sampling events between September 10, 1999 and October 21, 1999 were provided by the MDEQ. In January 2000, the MDEQ collected additional samples from four locations in Portage Creek and seven locations in the Kalamazoo River that were analyzed for PCB homologs.

Additional, extensive surface water sampling is presently being conducted by the KRSG in the Kalamazoo River and its tributaries. This work includes base flow and precipitation event-flow sampling, biweekly monitoring at 13 locations, TOC data collection, tributary solids loading, and other activities. These studies will provide the largest and most comprehensive surface water database for the Kalamazoo River to date, and were designed specifically to assess the factors affecting PCB transport and to aid in the development of a sediment and PCB fate and transport model. The complete sampling effort is described in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e), along with a comparison of data collected from March through July 2000 to historical data.

4.5.1 Spatial Distributions of PCB Concentrations in Surface Water

Spatial trends of surface water PCB concentration are evident in surface water in the MDEQ data from the 1980s, in the 1994 RI and 1994/1995 LMMBS data, and in the recent 1999/2000 CDM data. The primary conclusions supported by these data are:

- PCB loading continues from upstream of the Site; and
- PCB concentrations increase within the Site and tend to decrease downstream of Lake Allegan.

The spatial distribution of PCB is illustrated on Figure 4-23, which presents PCB concentrations in surface water by river mile during high flow and low flow sampling events and as a total of all data. These figures show similar spatial gradients among studies, with the exception of the data from the 1980s, which did not include samples collected downstream of Lake Allegan and, therefore, cannot confirm a decreased concentration downstream of Lake Allegan.

1980s Surface Water Data

Surface water PCB data collected by the MDNR between 1985 and 1988 showed relatively higher PCB concentrations and a greater frequency of PCB detection (at a detection limit of 0.01 micrograms per liter [μg/L]) at several sample locations than was observed in subsequent data. Thirteen locations on the Kalamazoo River between River Street and M-118 (downstream of the Allegan City Dam) were sampled during 28 sampling events. Of the 101 samples collected, 30 surface water samples (30%) were reported as non-detect (at a detection limit of 0.010 μg/l) and 45 of the 101 samples (45%) with detectable PCB (21%) were less than the 1994 detection level of 0.025 μg/l. All non-detected PCB results in the 1980s occurred at the seven sample locations upstream of Plainwell Dam (30 of 62 samples reported as non-detect); downstream of Plainwell Dam all samples had detectable concentrations of PCB.

1994 RI Surface Water Data

> - PCB concentrations in surface water are relatively low – 74% of samples collected during the 1994 Remedial Investigation were reported as non-detect – and have been decreasing over time.
> - Upstream PCB sources are evident in measurable levels of PCB just below Morrow Lake.
> - Flow, temperature, and total suspended solids concentration are factors which affect the concentration of PCB in surface water.

Total PCB concentrations in Kalamazoo River RI surface water samples (see Figure 2-5 for locations) were low in relation to the method detection limit (MDL) and generally show an increasing downstream gradient in 1994. Figure 4-24 presents the frequency of PCB detections for all surface water samples by concentration and illustrates the large proportion of samples in which PCB were not detected during the 1994 RI. Approximately 74% of 1994 RI samples (106 of 143) from the Kalamazoo River were reported as having no PCB detected, and only two samples (1.4%) from the Kalamazoo River were reported as having total PCB concentrations greater than the USEPA Method 8081 (USEPA, 1990) quantitation limit of 0.050 μg/L reported by the laboratory. The primary detection limit used in the surface water investigation (0.025 μg/L) was determined from a special study using Kalamazoo River water. During the 1994 RI, PCB were detected less frequently in the upper reaches of the river: only 3% and 7% of the surface water samples from River Street (SWK-1) and Michigan Avenue (SWK-3A), respectively, and 22% of the samples at D Avenue (SWK-3) (only baseflow sampled). PCB were detected more frequently, but at relatively equal concentrations, in surface water samples collected within and downstream of the existing and former impoundments: PCB were detected in between 42% and 47% of samples from Farmer Street in Otsego, M-222 in Allegan (SWK-5), and M-89 (SWK-6).

1994/1995 LMMBS Surface Water Data

Total PCB concentrations based upon the LMMBS data collected near New Richmond in 1994 and 1995 are notably consistent with PCB concentrations observed downstream of Lake Allegan in the 1994 RI data. The average total PCB concentration for all samples collected as part of the LMMBS was 0.023 μg/L, while the estimated average of the RI data collected at Fennville was 0.024 μg/L.

1999/2000 MDEQ Surface Water Data

> ➢ PCB were detected in surface water from both upstream and downstream of KRSG facilities and OUs.

The surface water data collected by MDEQ in 1999 and 2000 exhibit the same spatial trends as the 1994 RI data and the historical MDEQ data (see Figure 4-23). These data also show continuing PCB loading from sources upstream of KRSG facilities as recently as January 2000. Of the 20 sampling locations on the Kalamazoo River, four were located upstream of KRSG facilities and OUs (Ceresco Dam, Morrow Dam, River Street, and Sprinkle Road). Analytical results for surface water samples collected at all four upstream locations indicated detectable concentrations of PCB. For example, a sample collected from the River Street sampling location had a total PCB concentration of 11 nanograms per liter (ng/L). This concentration was greater than 43% of all surface water samples collected within and downstream of the NPL Site. Of four sampling locations on Portage Creek, the Kilgore Road and Garden Lane sampling stations are located upstream of all KRSG facilities and OUs. The one 1999 sample collected by the MDEQ at Kilgore Road (upstream of KRSG OUs) had a total PCB concentration of 71 ng/L, which was the third highest PCB detection in surface water samples collected from the Kalamazoo River or Portage Creek since the late 1980s.

In January 2000, the MDEQ collected additional surface water samples along Portage Creek (four locations) and the Kalamazoo River (seven locations) for homolog-specific PCB analysis. Of the samples collected in the Kalamazoo River at locations upstream of KRSG facilities and OUs (River Street and Sprinkle Road), a total PCB concentration of 1.6 ng/L was detected in one sample collected near Sprinkle Road. The two locations on Portage Creek upstream of the NPL Site were Garden Lane and Kilgore Road. The sample collected near Garden Lane, at the upstream boundary of Bicentennial Park, had a total PCB concentration of 2.1 ng/L. Although three samples collected near Kilgore Road had non-detectable total PCB concentrations, the sample collected near Cork Street, at the upstream boundary of the Allied OU, had a total PCB concentration of 5.8 ng/L.

Summary

> ➢ Data collected in both 1994 and 2000 show lower, less variable PCB concentrations in surface water than were present in the mid- to late-1980s.

Although PCB concentrations in surface water were lower and less variable in both 1994/1995 and 2000 than in the mid-to-late 1980s (Figure 4-23), similar spatial trends are exhibited by data from all three time periods. The graphs show little change in PCB concentration between 1985-1988 and 1994 surface water sample results within the first 10 miles downstream of the River Street sampling location (1.2 miles downstream of Morrow Dam). However, the 1985-1988 data show notable increases in the downstream direction in surface water PCB concentration at both flow conditions beginning at 10th Street, Plainwell. The 1994 data for both baseflow and high-flow show a flatter, more consistent profile of PCB concentrations in the Kalamazoo River. A similar observation can be made with respect to the MDEQ 1999/2000 data. The consistency of low concentrations sustained in the downstream direction indicates a reduced availability of PCB in the Kalamazoo River for transport since the 1980s. It should be noted that periodic occurrences of elevated PCB concentrations were observed at River Street (1.2 miles below Morrow Dam) both historically and in 1994 (0.14 μg/L and 0.048 μg/L, respectively), indicating a continuing source of PCB upstream of the Site. Additional data collected in 2000 are incorporated into this comparison in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

4.5.2 Mechanisms of PCB Transport

> ➢ The transport of heavier, more highly chlorinated PCB is more associated with high-flow events and the movement of sediment.

PCB transport can occur as a result of partitioning from the sediment bed to the water column (dissolved flux) or as a result of sediment resuspension and transport (particulate phase flux). Physical properties affecting the transport of PCB are described in Appendix L. In the Kalamazoo River, most of the transport appears to be in the particulate phase, as evidenced by the LMMBS data.

Congener data from the LMMBS show distinct differences in the PCB compositions of particulate and dissolved-phase PCB. The average normalized congener distribution (congener percent of total concentrations) of all LMMBS samples is presented on Figure 4-25 for both the particulate and dissolved phases. As would be expected, the dissolved phase comprises mostly the lighter, less chlorinated congeners, which are more soluble in water. Conversely, the particulate phase PCB distribution exhibits fewer light congeners and more frequent detections of the heavier, more chlorinated congeners, which are less soluble and have a greater tendency to sorb strongly to organic matter than lighter congeners. These results, as well as the results of the LMMBS, support the observation that transport of the higher-molecular weight PCB is more closely tied to the movement of sediment and increasing flow.

The same trend is discernable in Aroclor data from the RI for both the Kalamazoo River and Portage Creek surface water. In general, the lower-number Aroclors are composed of a combination of lighter, less chlorinated congeners. Figure 4-26 presents a summary of the frequencies at which the PCB mixtures in surface water samples were "best fit" to various Aroclors (if a sample was quantified as more than one Aroclor, each is shown). In the Kalamazoo River, all the reported PCB concentrations during baseflow conditions were quantified as less-chlorinated Aroclor 1016. However, during high-flow events, approximately half of the PCB detections were quantified as Aroclor 1016, with the remainder quantified as the more highly chlorinated Aroclor 1242 (the PCB product most commonly associated with paper recycling) and Aroclor 1248.

Portage Creek data indicate the same patterns in baseflow and high-flow surface water samples. In Portage Creek baseflow samples, total PCB concentrations were nearly equally quantified as Aroclor 1016 (45%) and Aroclor 1242 (Figure 4-26). However, during high-flow events, PCB detections were quantified as Aroclor 1242 three times as frequently as Aroclor 1016 (62% and 19%, respectively). Also during high-flow events, five PCB detections were quantified as the more highly chlorinated Aroclor 1248, accounting for 19% of the high-flow PCB detections.

Factors Affecting PCB Concentrations in Surface Water

The concentrations of PCB in surface water are dependent on the magnitudes of dissolved and particulate-phase PCB. Due to the range of transport characteristics exhibited by the individual congeners and congener mixtures, dissolved and particulate-phase PCB can be affected by different factors. Factors affecting the dissolved PCB flux include temperature, while particulate-phase flux is at least in part dependent on flow and TSS. Understanding the relationship between PCB and any independent variables is necessary to allow for normalization of the PCB data and to facilitate more accurate comparisons of data over time. These factors (flow, temperature, and TSS) are discussed below relative to the individual data sets. Temporal trends in surface water PCB concentration are discussed in detail in Section 5.2.2.

4.5.2.1 Effects of Flow on PCB Concentration

The behavior of PCB concentration and transport in a river in response to fluctuations in flow depends on the mechanisms by which PCB enter the water column. Where sediments are the predominant source, PCB will enter the water column either chemically through desorption, diffusion, or advection of porewater PCB from the sediment; or physically through resuspension of sediments. PCB desorption from sediment is a relatively constant process under a given set of environmental conditions (such as temperature, sediment TOC, etc.), so increases in flow will provide dilution of such dissolved PCB (USGS, 1983). In contrast to the more consistent desorption process, PCB concentrations may increase in response to increases in sediment scour and resuspension typically experienced during high flows.

Although there appears to be some response of PCB concentration at very high and very low flows, the large number of samples in which no PCB were detected prevented a confident assessment of flow-PCB relationships in the 1994 data set. With respect to the data collected during the LMMBS conducted in 1994-1995, a significant inverse relationship between flow and PCB concentration was observed for dissolved, particulate, and total PCB concentration. The observed significant relationship can be attributed to the use of a more sensitive detection limit, which reduced the occurrence of non-detect values to 2 of 42 samples analyzed for dissolved PCB.

- It is difficult to establish a relationship between PCB concentration and flow in the 1994 RI data due to the high number of non-detects and the narrow range of concentrations.
- The 1994-95 LMMBS revealed an inverse relationship between flow and PCB concentration.

With respect to the 1994 surface water sampling investigation, flow variation in the Kalamazoo River at the time of PCB sampling had little apparent effect on the total PCB concentrations observed. Comparable PCB detections and non-detections were observed over a range of flows, as is apparent on Figure 4-27. For samples collected at the River Street and Michigan Avenue sampling locations, the small number of detectable PCB concentrations precluded the identification of trends. At D Avenue, all samples analyzed for PCB, with corresponding flow data, were reported as non-detect. At Farmer Street, M-222, and M-89, PCB were detected at generally higher concentrations and greater frequencies at low and high flows, suggesting the effects of dilution with increasing flow and scour at very high flows.

The longitudinal profile of PCB levels during baseflow and higher along the Kalamazoo River is illustrated on Figure 4-28. During 1994 baseflow sampling (i.e., flow <1,000 cfs at the USGS Comstock gage), the average PCB concentration increased gradually between River Street (4.5 miles) and D Avenue (14.7 miles), peaked at Farmer Street (27.0 miles), and decreased from Farmer Street to M-89 (57.8 miles). During 1994 high-flow events (i.e., flow >1,000 cfs), the average PCB concentration steadily increased along the river until gradually leveling off downstream of the Farmer Street sampling location, obtaining a maximum concentration at M-222 (45.6 miles) in Allegan. The maximum observed PCB concentrations during baseflow followed a similar trend seen with the average PCB concentrations. The apparent trend in maximum observed PCB concentrations during high-flow events, however, included a single detection at River Street and a gradual peak at M-222. As noted previously, the detection at the River Street location indicates a source of PCB upstream of the Site.

In Portage Creek samples, flow had little effect on the reported PCB concentrations. PCB concentrations varied considerably within the range of flows measured during the 1994 Surface Water Investigation (Figure 4-27). The relatively narrow distribution of flows measured at Michigan Avenue, Kalamazoo, hindered an evaluation of trends; for example, a majority of the flows were recorded between 50 cfs and 75 cfs, while corresponding PCB concentrations varied by approximately an order of magnitude (0.035 μg/L to 0.22 μg/L). Results of a regression analysis of flow and PCB concentration in Portage Creek show that there was not a statistically significant relationship between flow and PCB concentration ($p<0.05$).

A significant inverse relationship between flow and PCB concentration was observed in the results from the LMMBS. Total PCB concentrations were inversely related to flow, which ranged from 1,000 cfs to 4,000 cfs during the sampling period. Comparison of the particulate and dissolved fractions of PCB shows that variation in total PCB is largely attributable to variability in the particulate phase PCB. These data, presented on Figure 4-29, show that while the dissolved phase PCB concentration remains generally low (<10 ng/L) and decreases slightly with increasing flow, the particulate phase PCB concentration is higher at lower flows and substantially decreases at higher flows. The inverse relationship between flow and PCB concentration indicates that dilution of PCB is occurring with increased flows. The degree of statistical correlation with flow is similar between the two phases; the dissolved phase PCB is significantly negatively correlated with flow ($r^2=0.17$, $p<0.05$), as is the particulate phase PCB concentration ($r^2=0.16$, $p<0.05$). Results of the regression analysis of flow and total PCB, dissolved phase PCB, and particulate phase PCB concentration are provided in Table 4-5.

Aroclor 1242 = congener assoc. w/ commercial paper residual

When the total PCB concentration data results from the LMMBS are analyzed on a congener-specific basis, an interesting correlation with flow is observed. Figure 4-30 depicts the variation observed in the fraction of total PCB composed of non-Aroclor 1242 congeners with flow. Non-Aroclor 1242 congeners represent the subset of the theoretically possible 209 congeners that are specifically not associated with the commercial Aroclor 1242 mixture (Schulz et al., 1989). Upon review of Figure 4-30, it is apparent that the fraction of the particulate and dissolved phase PCB composed of non-1242 congeners increases with flow; with a more pronounced increase observed in the particulate phase. Results of a regression analysis show that a significant relationship exists between flow and the ratio of non-1242 congeners to total PCB in the particulate phase ($r^2=0.20$, $p<0.01$). This significant relationship can be attributed to increased scour and resuspension at high flow events; because observations suggest that the

Somewhat non-Aroclor 1242?

Not clear what they are concluding?

particulate phase PCB distribution exhibits more frequent detections of the heavier, more chlorinated congeners (Figure 4-25), which are less soluble and have a tendency to sorb strongly to organic matter.

> ➤ Surface water sampling initiated by the KRSG in spring 2000 will conclude in the spring of 2001.

Surface water sampling currently being performed by the KRSG began in the spring of 2000 and will conclude in the spring of 2001. This monitoring program was designed specifically to provide PCB data over a wide variety of flows, which will statistically define the relationship between PCB correlation and flow at various locations along the Kalamazoo River. This sampling effort and the results from early 2000 are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

4.5.2.2 Effects of Temperature and Season

> ➤ Both the LMMBS and 1994 RI data indicate that increases in water temperature lead to increases in PCB concentrations. This relationship follows a general seasonal trend; peak PCB concentrations occur between May and August.

Increases in water temperature are theoretically expected to increase the rate of desorption of PCB from sediment, producing a positive correlation between PCB concentration in the water column and temperature, other factors (e.g., flow) being equal.

In the Kalamazoo River, surface water PCB concentrations for samples collected during the 1994 Surface Water Investigation were positively correlated to water temperature at every sampling location. Results of a statistical analysis of PCB concentration and temperature show statistically significant ($p<0.05$) relationships at Farmer Street, M-222, and Portage Creek (Table 4-5). At Farmer Street in Otsego, where the correlation between temperature and PCB concentration was observed to be strongest ($r^2=0.32$, $p<0.001$), all but one of the PCB detections during high-flow events were observed during the August 13-24, 1994 event when the average water temperature was greater than 20°C. However, the highest reported PCB concentration occurred during baseflow conditions when the water temperature was recorded as 22°C.

The relationship between PCB concentration and water temperature is reflected in the general seasonal trend in surface water PCB concentrations, which was also evident in the Kalamazoo River data. Figure 4-31 presents the reported PCB concentrations for the Kalamazoo River during the Surface Water Investigation. Total PCB concentrations in surface water samples exhibited a general peak during the summer months (i.e., May – August) with a corresponding decrease in the occurrence of PCB non-detections during these months.

I can't see the "peak" in Fig. 4-31.

The frequencies of Aroclor quantification by temperature range are presented on Figure 4-26. Although the histogram includes samples from a wide range of flows, it is evident that the frequency of PCB quantified as Aroclor 1016 is directly related to temperature. The decrease of Aroclor 1016 at higher temperature is likely an artifact of fewer samples being collected at the extreme high temperatures, which do not frequently occur in the Kalamazoo River. The apparent shift in Aroclor distribution in relation to temperature and flow observed in the Kalamazoo River surface water samples was consistent with the relative importance of PCB desorption during summer or baseflow, and the increased relative importance of particulate-associated PCB transport during periods of cooler temperatures or higher flows.

Portage Creek exhibited a significant positive correlation between PCB concentration and temperature (r^2=0.18, $p<0.05$). Reported PCB concentrations were highest in June, July, and August. The arithmetic average PCB concentration during these three months was 0.14 μg/L compared with 0.073 μg/L for the remaining nine months. Results of the regression analysis are presented in Table 4-5.

Portage Creek PCB concentrations quantified as Aroclor 1242 were positively related to temperature. The highest reported concentrations of PCB quantified as Aroclor 1242 coincided with the warmer temperatures, regardless of flow conditions. PCB quantified as Aroclor 1016 also increased in frequency and concentration at temperatures greater than 15°C. PCB quantified as Aroclor 1248 were not strongly related to temperature and appeared to occur in response to high-flow events only (Figure 4-26).

The LMMBS data collected at New Richmond showed significant relationships between PCB concentrations and temperature for dissolved phase PCB (r^2=0.45, $p<0.001$), particulate phase PCB (r^2=0.23, p=0.002), and total PCB (r^2=0.30, $p<0.001$) based on the results of regression analysis (Table 4-5).

To assess seasonal trends of PCB concentration, LMMBS PCB data were compared between the typically warm weather months (i.e., May, June, July, and August) and all remaining months. During the warmer months, the observed total PCB concentrations ranged between 0.0072 μg/L and 0.047 μg/L, with an average concentration of 0.028 μg/L. Conversely, in the remaining eight months, the observed total PCB concentrations ranged between 0.0060 μg/L and 0.039 μg/L, with an average concentration of 0.018 μg/L.

Based on the data results and regression analyses presented above, PCB concentration in surface water is positively correlated with temperature in the Kalamazoo River and Portage Creek. Significant

> ➢ The goals of the ongoing KRSG surface water investigation are to identify factors affecting variations in PCB concentrations and clarify the effects of temperature.

relationships between PCB concentration and temperature were not generally observed in the 1994 RI results, which can be attributed to the greater number of samples collected in warmer months than colder months and the large proportion of PCB non-detections; however, the relationship between PCB concentration and temperature is reflected in overall seasonal trends. Additional ongoing surface water sampling by the KRSG was designed specifically to identify factors affecting the variation of PCB concentration. This sampling effort and results from early 2000 are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

4.5.2.3 Effects of Sediment Resuspension/TSS

> ➢ No meaningful correlation exists between PCB concentrations in Kalamazoo River surface water and levels of total suspended solids.

In theory, if sediment resuspension is an important determinant of PCB concentration in surface water, positive correlations between PCB and TSS should exist. However, no meaningful correlations ($p<0.05$) between PCB and TSS in the Kalamazoo River were established through regression analyses of the 1994 RI data or the data collected near New Richmond as part of the LMMBS. TSS levels were generally consistent regardless of location and flow conditions and showed little variation from which a meaningful relationship with PCB concentration could be derived.

Does this indicate the statistical analysis isn't calibrated in reality? or maybe the data set isn't good enough to show the correlation?

For Portage Creek, a significant relationship between TSS and PCB was observed ($r^2=0.15$, $p<0.05$). TSS levels were observed to be greatest at flows over 100 cfs (4 samples) and varied widely when flows were less than 100 cfs. TSS levels were responsive to flow events in Portage Creek, but PCB concentrations were not. The highest and lowest PCB concentrations were observed during lower flows, but detectable PCB concentrations were also reported for increased flows.

An annual TSS loading balance was developed for the Kalamazoo River between Galesburg and Lake Allegan by LTI using available STORET data, hydrology data from the Michigan Resource Information System (MIRIS), and RI data. TSS loading was estimated for monitored tributaries based on TSS data and flow data available from USGS. TSS loading for ungaged tributaries was estimated using rating curves developed for nearby monitored tributaries and accounting for differences in drainage area. Based on data gathered from 1985 through 1999, it is estimated that of the approximately 27,200 metric ton annual TSS load entering the Kalamazoo River between Galesburg and Lake Allegan, approximately 47% (12,780 metric tons) originates from upstream of Morrow Lake. Of the remaining 53%, it is estimated that approximately 31% (8,400 metric tons) of the solids load is contributed by major tributaries, approximately 9% (2,450 metric tons) is contributed by small tributaries, and the remaining 13% (3,500 metric tons) is contributed by direct drainage into the river (i.e., overland runoff). Of the tributaries, Gun River is the largest source of solids, contributing approximately 14% (4,100 metric tons) of the annual load entering between Galesburg and Lake Allegan, followed Pine Creek which contributes an estimated 2,600 metric tons per year (10% of total). By comparison, Portage Creek is estimated to contribute only 1.9% of the total estimated load in the Kalamazoo River within this reach.

The relationship between PCB concentration and TSS was not significant ($p<0.05$) in surface water samples collected near New Richmond as part of the LMMBS. The lack of a significant relationship between TSS and PCB may be attributed to contributions of suspended solids from the Rabbit River, located just upstream of the sampling location. Determinants of correlation (i.e., r^2) values ranged from 0.003 to 0.067. Results of the regression analysis of the 1994 RI and LMMBS data are presented in Table 4-5.

Seems like the LMMBS data set is better than BBL's???

Additional samples collected by the KRSG in 2000 will be analyzed for PCB and TSS to allow evaluation of their relationship at several locations. This sampling effort and results from early 2000 sampling are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

An attempt to improve the data set?!

Do we have a good enough data set to complete this?

4.5.2.4 Multivariate Regression Analysis

A multivariate regression model was used to examine the relative importance of flow, temperature, and TSS in explaining the variation of PCB concentrations in surface water samples. For each sampling location, PCB concentrations were evaluated as the dependent variable against flow, temperature, and TSS as the independent variable. The results of this analysis are provided in Table 4-5. Results of the regression would take into account any effect of covariance between the independent variables.

Do we need all the statistical analysis?

For the Kalamazoo River 1994 RI data, the multivariate regression including flow, temperature, and TSS was not significant ($p<0.05$) in predicting PCB at any sampling location. Summary statistics of the multiple regression and the regressions of individual parameters are provided in Table 4-5 and the results summarized in the table below. The combination of flow, TSS, and temperature accounted for 19% to 34% of the variation observed in surface water PCB concentration at Farmer Street, M-222, or M-89. TSS and flow individually did not significantly contribute to the multivariate regressions at any location, with less than 1% to 50% and 5.6% to 16% of the model variation in PCB concentration being attributed to TSS and flow, respectively (see table below). With respect to temperature, significant contributions to the prediction of surface water PCB concentrations were observed at Farmer Street ($p<0.05$) and M-222 ($p<0.05$). The percent variation explained by the model caused by temperature ranged from 2.6% to 85%.

For Portage Creek, the multivariate regression indicated TSS and flow to be significant factors in predicting the variability of PCB concentration in surface water ($p<0.05$). Approximately 30% of the PCB variation in Portage Creek can be explained by the combination of TSS, flow, and temperature interactions. Of the PCB variation explained by the model, TSS and flow contributed approximately 35% and 25%, respectively. In addition, temperature was observed to not significantly influence PCB concentrations in Portage Creek surface water.

The multivariate regression indicated that the model was significant in predicting PCB concentrations from the LMMBS data. The results of the analysis showed that 41%, 35%, and 50% of variations in PCB concentrations could be explained by the model for total PCB, dissolved PCB, or particulate PCB, respectively. TSS did not significantly contribute to variations of total, particulate, and dissolved PCB (<1%, 12%, and <1%, respectively) when included with temperature and flow. Flow was observed to contribute significantly (<0.05) to the total PCB and particulate PCB models, accounting for 21% and 24% of the model variation, respectively, but not the dissolved PCB regression. Temperature had a significant influence on each LMMBS model with between 33% and 60% of the model variation being attributed to temperature.

Location	Year Sampled	Analysis	Number of Samples	p-value of Model	Percent of PCB Variability Explained by Model	Percent Contribution to PCB Variability Explained by Model		
						TSS	Temperature	Flow
RI Surface Water Investigation								
Farmer St.	1994	Total PCB	31	0.009	34	<1.0	78	5.6
M-222	1994	Total PCB	24	0.080	28	12	85	14
M-89	1994	Total PCB	12	0.61	19	50	2.6	16
Portage Creek	1994	Total PCB	31	0.022	30	35	13	25
Lake Michigan Mass Balance Study								
Near New Richmond	1994-1995	Total PCB	38	<0.001	41	<1.0	40	21
Near New Richmond	1994-1995	Particulate PCB	38	0.002	35	12	33	24
Near New Richmond	1994-1995	Dissolved PCB	38	<0.001	50	<1.0	66	9.5

Ongoing surface water sampling efforts were designed to provide a complete year-long data set on which statistically robust multivariate analyses can be performed. This sampling effort and results from samples collected from March through July 2000 are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

4.5.3 Trends in Surface Water PCB

Surface water PCB concentrations and transport have significantly declined in the Kalamazoo River, based on the MDNR's 1980s data, 1994 RI data, and 1999/2000 MDEQ data. Results of a regression analysis of the MDEQ's

What do we need to know to make a clean-up decision? How relevant is most of this discussion?

1980s and the 1994 RI data suggest that the average PCB concentrations at locations within and below the existing and former impoundments have decreased significantly ($p<0.05$). Further support for this observed trend is based on the comparison of the MDEQ's 1985-88 data and 1999/2000 MDEQ data, which indicates average PCB concentrations have decreased over time from 0.062 μg/L to 0.016 μg/L at the Plainwell Dam, from 0.060 μg/L to 0.018 μg/L at Farmer Street, from 0.075 μg/L to 0.018 μg/L at the Otsego Dam, and from 0.087 μg/L to 0.023 μg/L at 25th Street (upstream of the Trowbridge Dam).

Mean surface water PCB concentrations at each location sampled during the historical, 1994 RI, and 1999/2000 MDEQ ~~investigations for base~~flow, high-flow, and all flow ranges are provided on Figure 4-23. As discussed in *Draft Technical Memorandum 16* (BBL, 1995a), the 1994 surface water investigation targeted the collection of surface water samples of both baseflow and high flow conditions. Baseflow conditions represent days of data collection when flow at the USGS River Street gage was less than 1,000 cfs, and high-flow represented flows above 1,000 cfs The data depicted on Figure 4-23 further illustrate the trend of reduced PCB concentrations in surface water over time. Additional data collected by the KRSG in 2000 are added to this figure in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

4.5.4 Other Constituents in Surface Water

> ➢ Surface water samples were also analyzed for:
>
> - Pesticides
> - VOCs
> - SVOCs
> - Metals

No pesticides, VOCs, or SVOCs were detected in any surface water sample. TAL analytes were analyzed in two samples from each sampling location: the September 1, 1994 baseflow sample and a high-flow sample collected August 13, 1994. A summary of the concentrations of TAL analytes detected in surface water samples was presented in *Draft Technical Memorandum 16* (BBL, 1995a) along with the Michigan Rule 57(2) screening levels in effect at the time the document was written (MDNR, 1994). Cyanide, mercury, and silver were detected concentrations exceeding the Rule 57(2) screening levels (MDNR, 1994) in a few surface water samples. One surface water sample contained lead at a concentration equal to the screening level.

In February 2000, the surface water TAL data were compared to updated criteria and the revised comparison was submitted to the MDEQ (BBL, 2000b). Based on a comparison to the current Rule 57 Human Non-Cancer, Non-Drinking Water Guidelines (MDEQ, 1999), which are the same as those presented in MDEQ, 2000b for analytes of concern (except thallium - which changed to "insufficient data to derive value"), only the mercury criterion was exceeded. In the four samples in which mercury was detected, concentrations exceeded the guideline value of 0.0018 μg/L.

4.6 Biota

Biota investigations include the sampling of aquatic biota (fish and snapping turtles) and terrestrial biota (earthworms and mice).

what about mink?

4.6.1 PCB in Fish

> - PCB were detected in fish samples collected in 1993 at each location upstream and downstream of the Site.
> - Most PCB detected in both upstream and downstream fish samples in 1993 and 1997 is from sources other than paper recycling. This indicates one or more sources of PCB exists upstream of the Site and paper recycling facilities.

Because of their central role in human health and ecological risk exposure pathways, fish have been the subject of a number of sampling and analysis surveys. The following subsections describe the results of these fish investigations conducted for the Kalamazoo River. In particular, this section focuses on the fish investigations conducted by the KRSG in 1993 and 1997. Additional fish sampling was performed by the KRSG in 1999 using the same sampling and analysis protocols as in 1993 and 1997. These data are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). The results of earlier investigations (i.e., those conducted by the MDNR) were previously described in the DCS (BBEPC, 1992). Data from the KRSG fish investigations are used in Section 5.2.3 to evaluate temporal trends in fish PCB data, including the 1993, 1997, and the historical MDNR data. Descriptions of each year's fish data are presented below, along with statistical analyses of spatial trends (i.e., comparison between locations), and an evaluation of factors affecting fish tissue PCB concentrations.

4.6.1.1 1993 Fish Data

In 1993, a total of 363 fish samples were collected from 11 ABSAs (see Figure 2-5 for locations). The target species included smallmouth bass (skin-on fillets), carp (skin-off fillets), and suckers, including white sucker, golden red horse, northern hog sucker, and spotted sucker (whole-body composite samples). The results of the 1993 fish investigation were described in *Draft Technical Memorandum 14* (BBL, 1994f). A summary of the 1993 fish data is presented in Table 4-6, and mean wet-weight and lipid-adjusted PCB concentrations for carp and smallmouth bass by location are presented on Figure 4-32. The process of lipid adjusting is commonly used in the assessment of gradients and trends in fish PCB levels because the fat content in fish generally accounts for some of the variation in wet-weight PCB levels within and between species. Carp and smallmouth bass data are much more comparable when lipid adjusted. In addition, the confidence limits around the relative to the mean tend to become smaller when lipid-adjusted. The vast majority of fish collected from the Kalamazoo River in 1993 were free of external abnormalities and in good health (BBL, 1994f). ?! with the levels of PCBs in Fig 4-32?!

PCB were detected in each of the fish samples from each ABSA, with the exception of one white sucker sample from the background location upstream of Battle Creek (ABSA 1). PCB concentrations in the 1993 fish samples were quantitated as various combinations of Aroclors, with PCB quantified as Aroclor 1254 and (to a lesser extent) Aroclor 1260 accounting for most of the PCB.

PCB levels were generally higher downstream of the Morrow Dam than upstream (Figure 4-32). Wet-weight and lipid-adjusted PCB concentrations were lowest near Battle Creek (ABSA 1) and highest downstream of Morrow Lake. Mean lipid-adjusted PCB concentrations in Morrow Lake (ABSA 2) smallmouth bass and carp were 3.8 and 7 times the respective mean concentration observed near Battle Creek (ABSA 1).

Downstream of the Morrow Dam there was no clear and consistent trend in wet-weight and lipid-adjusted PCB concentrations across the three species. Arithmetic mean wet-weight PCB concentrations were highest downstream of the Allegan Dam (ABSA 10) and in Lake Allegan (ABSA 9) for carp and smallmouth bass, respectively (Figure 4-32). Wet-weight PCB concentrations in sucker species were highest at Mosel Avenue (ABSA 4). For both smallmouth bass and carp, lipid-adjusted PCB concentrations were highest in Lake Allegan (ABSA 9). Lipid-adjusted PCB concentrations in suckers were highest just upstream of the Trowbridge Dam (ABSA 8). The arithmetic mean wet-weight PCB concentration in smallmouth bass in Morrow Lake (ABSA 2) was between 8% and 34% of those reported from downstream locations. The arithmetic mean lipid-adjusted PCB concentration in Morrow Lake (ABSA 2) smallmouth bass was between 15% and 55% of concentrations reported at downstream locations. For carp, the arithmetic mean wet-weight PCB concentration in Morrow Lake (ABSA 2) was between 8% and 58% of those reported for downstream locations, while the arithmetic mean lipid-adjusted PCB concentration for Morrow Lake carp was between 18% and 64% of those from downstream locations.

4.6.1.2 1997 Fish Data

In 1997, 136 fish samples were collected from five ABSAs (1, 2, 5, 9, and 11). Target species included smallmouth bass (skin-on fillets), carp (skin-off fillets), and yearling smallmouth bass (whole-body composite samples). The results of the 1997 fish investigation were described in *Draft Addendum 3 to Draft Technical Memorandum 14* (BBL, 1998). A summary of the 1997 fish data is presented in Table 4-7, and mean wet-weight and lipid-adjusted PCB concentrations for each species and location are presented on Figure 4-33. PCB were detected in all fish from each ABSA, with the exception of one smallmouth bass from Battle Creek (ABSA 1) and one carp fillet from Morrow Lake (ABSA 2). Similar to the 1993 collections, the great majority of fish collected in 1997 (i.e., 70% of carp and 34% of smallmouth bass) were free of external abnormalities.

The pattern of Aroclor quantitation in fish tissue suggests the contribution of Aroclor 1254 and Aroclor 1260 sources. The quantitation of PCB as primarily Aroclors 1254 and 1260 was observed in fish from Battle Creek (ABSA 1) and Morrow Lake (ABSA 2) (both upstream), and in significant proportions in fish from all ABSAs (refer to Appendix K). Conversely, little or no Aroclor 1242 or 1248 were quantified in fish samples collected upstream of the City of Kalamazoo.

Average PCB concentrations were lowest in fish collected near Battle Creek (ABSA 1) and generally increased in a downstream direction. The arithmetic mean wet-weight and lipid-adjusted PCB concentrations in smallmouth bass and carp were 2.3 to 4.6 times higher in Morrow Lake (ABSA 2) than near Battle Creek (ABSA 1). Downstream mean lipid-adjusted carp PCB concentrations were 7.9 to 14 times those observed at Battle Creek, and mean lipid-adjusted smallmouth bass PCB concentrations were 11 to 21 times Battle Creek concentrations. Morrow Lake fish concentrations more closely resemble the downstream locations; the mean wet-weight PCB concentration in smallmouth bass from Morrow Lake was 20% to 24% of those at downstream locations. In Morrow Lake carp, wet-weight concentrations ranged from 4% to 36% of the downstream averages. The arithmetic mean lipid-adjusted PCB concentration in Morrow Lake smallmouth bass was between 11% and 22% of concentrations reported at downstream locations. The arithmetic mean lipid-adjusted PCB concentration for Morrow Lake carp was between 36% and 62% of concentrations reported at downstream locations.

4.6.1.3 1999 Fish Data

Additional fish sampling was performed by the KRSG in 1999 using the same sampling and analysis protocols as in 1993 and 1997. In addition to collecting carp and smallmouth bass for trend monitoring purposes, a wider array of species were collected based upon the reported preferences of Kalamazoo River anglers (ATSDR, 2000). These data have been submitted to the MDEQ and are presented and discussed in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

4.6.1.4 Determinants of Fish Tissue PCB Concentrations

> ➢ Upper-trophic level species and bottom feeders tend to have the highest PCB concentrations.

A number of factors affect PCB bioaccumulation in fish. These include the availability of PCB within various media (e.g., food items, water, sediment) in the aquatic environment, and the characteristics of fish, such as life history, migratory and other behavioral patterns, diet (or, more generally, trophic level), metabolic rate, and lipid content. It is important to understand the potential influence of these factors when attempting to evaluate trends in fish PCB concentrations.

One of the largest factors affecting fish tissue PCB concentrations is the feeding behavior of the species. In general, upper-trophic level species (e.g., smallmouth bass) and bottom feeding species (e.g., carp) have higher PCB concentrations than mid- to lower-trophic level species. See the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e) for the results of a more comprehensive sampling across trophic levels to include species and tropic levels not represented in the 1993 and 1997 collections.

> ➢ The fat content (lipid concentration) tends to be the most important variable in explaining the often wide range of results in PCB concentrations found in a species at a particular location.

A series of regression analyses were performed in *Draft Technical Memorandum 14* (BBL, 1994f) to evaluate the potential effects of other various factors on fish tissue concentrations. Linear regressions were performed for each fish species at each ABSA to evaluate the contribution of fish length, weight, K value, and lipid content to the variation of PCB concentration. Coefficients of determination (r^2) values from the regression analyses of the 1993 data are presented in Table 4-8. Similar regressions were also conducted for the 1997 fish data (Table 4-9) and the 1999 fish data presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). The results of the regression analyses indicate that lipid content is more strongly correlated with total PCB concentrations in fish than the other parameters, although lipid content alone does not always account for a significant portion of the variability in wet-weight PCB concentrations.

The ~~coefficients of variation (CVs)~~ for wet-weight ~~PCB and~~ lipid-adjusted PCB concentrations have been calculated for the 1993 data (Table 4-6) and 1997 data (Table 4-7). Collectively, the CVs indicate that, in general, the variability of PCB per unit lipid are almost always less than that of wet-weight PCB concentration. This observation indicates that lipid-adjusted fish PCB concentrations may be more sensitive than wet-weight PCB concentrations when monitoring potential trends in PCB bioavailability. Also, both wet-weight and lipid-adjusted total PCB concentrations are generally less variable for smaller and younger fish (i.e., juvenile suckers and smallmouth bass) in comparison to adult smallmouth ~~bass and~~ carp.

As shown in a special study of Kalamazoo River fish (BBL, 1994f), the differences in lipid content also explain the differences between types of analyzed samples. In general, whole-body samples have higher PCB concentrations than fillet samples, and skin-off fillet samples have lower PCB concentrations than skin-on fillets. The differences between sample types is a reflection of the preferential accumulation of PCB in fattier tissue, which is generally located in the viscera and just underneath the skin.

May want to see this citation

The decline in Kalamazoo River fish PCB levels over time, which has been noted by others (ATSDR, 2000), is analyzed in Section 5.2.3 of this report as well as in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

4.6.2 Other Constituents in Fish

> - All fish samples collected in 1993 were also analyzed for:
>   - Chlorinated organics
>   - Mercury
>   - Pesticides
> - Fish having the highest PCB concentrations were also analyzed for chlorinated dioxins.

All of the fish samples collected as part of the 1993 fish monitoring program were analyzed for other constituents, including chlorinated organic compounds and mercury. A subset of samples having the highest PCB concentrations at each location were analyzed for PCDD/PCDF. Of the 17 compounds included in the analytical program, three of the compounds (i.e., 4-bromobiphenyl, hexabromobiphenyl, and toxaphene) were not detected in any of the fish species submitted for analyses. Although several pesticides were detected in the 1993 fish samples, concentrations varied with location and fish species, and were consistently below 0.1 mg/kg throughout the study area. None of the smallmouth bass or carp contained dieldrin or DDT at concentrations exceeding MDCH trigger levels. A single carp sample (0.31 mg/kg) collected downstream of Lake Allegan Dam exceeded the 0.30 mg/kg MDCH trigger level for heptachlor epoxide, and four carp exceeded the 0.30 mg/kg MDCH trigger level for total chlordane (concentrations ranging from 0.32 to 0.78 mg/kg).

Mercury was detected in all fish samples. However, none of the carp samples and only a single smallmouth bass specimen (0.89 mg/kg) from Morrow Lake exhibited a mercury concentration greater than the MDCH trigger level of 0.50 mg/kg in fish.

For each ABSA, the smallmouth bass fillets and carp fillet samples with the highest PCB concentration were analyzed for PCDD/PCDF to assess potential risks to consumers of Kalamazoo River biota. These results were presented in *Draft Addendum 2 to Draft Technical Memorandum 14* (BBL, 1995c). The total tetrachlorinated dibenzo-p-dioxins (TCDD)-equivalent concentrations for Kalamazoo River fish indicated that for smallmouth bass (maximum concentration of 5.7 nanograms per kilogram [ng/kg]), all of the samples collected in the Kalamazoo River had concentrations below the MDCH trigger concentration of 10 ng/kg. Two of the eleven carp samples from the Kalamazoo River (total TCDD-equivalent concentrations of 23 ng/kg and 20 ng/kg) exceeded the MDCH trigger concentration, but did not exceed the current U.S. Food and Drug Administration (USFDA) tolerance level of 25 ng/kg. The carp sample from Portage Creek, with a total TCDD-equivalent concentration of 2.8 ng/kg, fell below the MDCH trigger concentration.

4.6.3 PCB in Turtles

This subsection presents the findings of PCB analyses conducted on snapping turtle samples. Muscle-only and whole-body samples of snapping turtles were used to assess spatial gradients.

The highest snapping turtle wet-weight PCB concentration (8.1 mg/kg) was reported in an individual sample from the upstream sampling location at Battle Creek (ABSA 1). This result was just slightly higher than a sample collected from a downstream location along the Kalamazoo River in Swan Creek Marsh (ABSA 10), which had a reported wet-weight PCB concentration of 7.9 mg/kg. Calculated mean wet-weight PCB concentrations for snapping turtle muscle-only samples tended to decline from the upstream (1.4 mg/kg at Battle Creek) to downstream locations (0.75 and 0.14 mg/kg for Plainwell and Swan Creek Marsh). Conversely, calculated mean wet-weight PCB concentrations for snapping turtle whole-body samples tended to increase from upstream to downstream locations. Similar trends were observed when the whole-body and muscle-only wet-weight PCB concentrations were adjusted for lipid content. Multivariate analyses conducted on the wet-weight and lipid-adjusted PCB concentrations, with respect to sampling location, failed to detect any significant differences between PCB concentration and sampling location for either whole-body or muscle-only snapping turtle samples.

The results of wet-weight PCB concentrations in muscle-only samples of snapping turtles were compared to the USFDA tolerance level of 2.0 mg/kg wet-weight PCB for edible portions (i.e., excluding viscera, bones, shell, etc.) to determine the frequency in which snapping turtle muscle samples exceed the tolerance level. Of the 18 muscle-only samples collected, only one sample collected at Battle Creek exceeded the USFDA tolerance level.

4.6.4 Other Constituents in Turtles

The snapping turtle muscle samples in each ABSA with the highest PCB concentrations were analyzed for PCDD/PCDF. The TCDD-equivalent concentrations for Kalamazoo River turtles indicated that all of the snapping turtle samples collected in the Kalamazoo River had concentrations below the MDCH trigger concentration of 10 ng/kg.

4.6.5 PCB in Terrestrial Biota

> ➢ Mice and earthworms were found to be accumulating relatively little PCB. In the exposed sediments of the MDNR-owned former impoundments, mice and earthworm PCB concentrations were approximately 1 percent and 10 percent of the PCB levels in the soil on or in which these organisms were found.

Results of the terrestrial biota investigation indicate that the highest soil, earthworm, and mouse mean PCB concentrations were observed in TBSAs 3 and 5, both of which are located within the former Trowbridge Impoundment. The lowest mean PCB concentrations were observed in TBSA 1, located downstream of Lake Allegan Dam, the dam farthest downstream on the Kalamazoo River. Results of the Terrestrial Biota Investigation are reported in *Draft Technical Memorandum 14* (BBL, 1994f).

PCB levels in both mice and earthworms collected from the exposed sediments of the former Trowbridge and Plainwell impoundments were substantially lower than the levels of PCB found in soils at the same locations shown in the table below.

Location	Average PCB Levels (mg/kg)		
	Soil	**Earthworm**	**Mice**
Trowbridge (TBSA3)	24	2.6	0.12
Trowbridge (TBSA5)	27	1.9	0.26
Plainwell (TBSA10)	6.5	0.46	0.092

Bioaccumulation factors (BAFs), the ratios of PCB levels in the organism to the PCB levels in the soils, ranged from 0.07 to 0.11 for earthworms and 0.005 to 0.014 for mice.

4.7 Sources of PCB to the Site

During the course of the RI, information pertinent to the assessment of current PCB sources to the Site was collected and analyzed, including:

- Identification of known and potential sources of PCB to the Site, including past and present point-source discharges and on-going non-point sources;

- Results from investigations of potential source areas currently or formerly owned by KRSG members; and
- Sediment and fish PCB data that provide empirical evidence of discharge of PCB from sources other than KRSG facilities or operations.

mills, landfills, what else?

What about KRSG waste in river? Is that considered to be "source"?

This information shows that: 1) KRSG sources have been controlled, or will soon be controlled, due to a series of response actions already accomplished or under way, 2) the predominant known external source of PCB to the Kalamazoo River today is the miles of eroding and erodible riverbank created by the MDNR's operation of its three former dams and related impoundments, and 3) uninvestigated point and non-point sources upstream of the Site and elsewhere in the watershed may still be significant with respect to sustaining the levels of PCB observed in fish. A more detailed discussion of these external PCB sources to the River is provided in Appendix K.

DNR didn't create the contam. riverbank, however.

4.7.1 Investigation and Remedial Activities at KRSG Mill Properties and OUs

The six KRSG mills (and related properties) and the four OUs within the Site have been, or will soon be, eliminated as potential sources of PCB to the Kalamazoo River. Active use of the OUs has ceased, and each mill property and OU has separate remedial programs complete or underway. Remedial activities at these locations include the consolidation of residuals into landfills or OUs, stabilization of berms, capping and closing of landfills or OUs, removal of material from the sediment bed immediately adjacent to some OUs, and the complete removal of sediment from the former Bryant Mill Pond.

Remedial Activities at KRSG Mills and Related Areas

Location	Action	Status
Former Allied Paper, Inc. Bryant Mill (Portage Paper Mill)	None, per MDNR	Complete
Former King Mill	Excavated 11,000 cy	Ongoing
Georgia-Pacific Kalamazoo Mill	Excavated >33,000 cy	Complete
Plainwell Mill	Cleaned storm sewers	Complete
King Street Storm Sewer	Excavated 5,000 cy	Complete
Former Allied Paper Company Monarch Mill	None, per MDEQ	Complete
Allied OU	Capped 18-acre landfill	Complete
	Stabilized berms	Complete
	Excavated 150,000 cy from Bryant Mill Pond	Complete
	Final landfill closure	Ongoing
KHL-OU	Landfill closure	Construction complete
WB/A-OU	Excavated 7,000 cy of sediment	Complete
	Stabilized berms at A-Site	Complete
	OU closure	Ongoing
12th Street Landfill OU	Landfill closure	Ongoing

Sorry, but the waste the KRSG mills discharged to the river is also their responsibility ⇒ CERCLA.

Such efforts at the mills and OUs include a number of voluntary source-control activities to eliminate the properties as potential sources of PCB to the Kalamazoo River. While voluntary efforts were typically performed in advance of the issuance of a Record of Decision (ROD) or AOC, all work was performed with MDEQ oversight and accompanied by environmental monitoring of water, air, or soils. The remedial work also involved cooperation with local residents and property owners. A summary of the actions taken at each of the mill properties and OUs is provided below and described in more detail in Appendix K, *Technical Memorandum 15 – Mill Investigations* (BBL, 1996a), and the separate RI/FS documents prepared for each OU.

Former Allied Paper, Inc. Bryant Mill (Portage Paper Mill). As directed by the RI/FS Work Plan (BBEPC, 1993f), several locations at the former Allied Paper, Inc., Bryant Mill were to be sampled to evaluate the presence of PCB associated with the wastewater and process water conveyances. However, historical residuals had already been removed from the Bryant clarifier in May 1992. Therefore, when the sampling team and an MDNR representative visited, there were little or no historical residuals observed in the proposed sampling locations. As a result, the MDNR determined that it was not necessary to collect samples, and no remedial response actions were performed at the former Allied Paper, Inc. Bryant Mill.

Former Allied Paper Company Monarch Mill. Based on RI sampling, the MDEQ determined that no remedial response actions were warranted for the former Allied Paper Company Monarch Mill (BBL, 1996a).

Former King Mill. Based on RI sampling data, and administered under the KHL-OU AOC (MDEQ, 2000a), voluntary remedial response actions were conducted at the former King Mill to remove PCB-containing residuals and soils in two former lagoons located east of the former plant. In the fall of 1999, approximately 11,000 cy of residuals were excavated from Lagoon EW and disposed of at the KHL-OU. After removing the residuals, the area was backfilled, graded, and revegetated. It is anticipated that additional removal activities will be undertaken to remove residuals remaining at the property.

Georgia-Pacific Kalamazoo Mill. Based on RI sampling data and administered under the KHL-OU AOC (MDEQ, 2000a), PCB-containing residuals were excavated and removed from six former lagoons on mill property adjacent to the Kalamazoo River that had historically received process wastewater from the mill. Between November 1998 and September 1999, approximately 33,000 cy of residuals were excavated from the lagoons and disposed of at the KHL-OU. In addition, approximately 5,000 cy of PCB-containing materials in the floodplain adjacent to the lagoons were excavated and consolidated at the KHL-OU. Post-removal verification sampling of the six former lagoons showed compliance with the 9.9 mg/kg criterion established by the MDEQ. After removing the residuals, both areas were backfilled, graded, and revegetated. Along the riverbank, about 400 feet of riprap (5 feet wide and 6 inches thick) was placed on top of geotextile to stabilize shoreline soils.

where did DEQ come up w/ this #?

Plainwell, Inc. Mill. Voluntary remedial response actions at the Plainwell, Inc. Mill consisted of taking PCB-containing sediment from a storm water outfall on the Mill Property. As part of the mill's maintenance, the storm water conveyances were cleared out and the sediment was disposed of properly. Sediment that had collected in a sump along the outfall was cleaned out in December 1995. Sediment that subsequently accumulated in the sump was sampled in October 1996 and was found to contain PCB at a concentration of 7.2 mg/kg (Brown, 1996b). Based upon these results, all drainage pipes leading to that outfall were cleaned using a high-pressure washer system in November 1997, and the sediment and flush water were appropriately disposed of off-site (Cowin, 1998).

King Street Storm Sewer (KSSS). Based on RI sampling, and administered under the KHL-OU AOC (MDEQ, 2000a), voluntary remedial response actions at the KSSS consisted of the removal of PCB-containing soils/residuals from this area adjacent to the Kalamazoo River. In June 1999, approximately 5,000 cy of soils/residuals were excavated from the KSSS and disposed of at the KHL-OU. Post-removal verification sampling showed that the 1 mg/kg clean-up goal, established in the KHL-OU AOC, was achieved. After removal of the materials, the area was backfilled, graded, and revegetated, and approximately 550 linear feet of riprap (5 feet wide and 6 inches thick) was placed on top of geotextile along the river and outfall channel for stabilization purposes.

I didn't think KHL RAD had a clean-up goal — so why did the AOC have one?

Allied Paper, Inc. OU. Remedial response actions conducted in the 1980s and early 1990s at the Allied OU consisted of the removal and disposal of PCB-containing residuals and sediments, stabilization of disposal area berms along Portage Creek, extraction and treatment of surface water, and construction of a landfill cap over former residuals dewatering lagoons occupying approximately 18 acres of the site. An erosion control plan was voluntarily implemented at the former Type III Landfill area of the OU in 1991. This effort included construction of a soil cap, drainage swales, and storm water retention basins; grading of the landfill cap; and seeding with erosion control vegetation. Other voluntary actions in 1991 and 1992 included seeding of the former lagoon areas of the OU to stabilize soils and facilitate evapotransportation. In 1993 and 1995, gabion baskets were installed on both sides of Portage Creek to stabilize the berm near the Bryant Historic Residuals Dewatering Lagoon (HRDL) and Monarch HRDL.

Not really accurate / MHI cashed out.

Pursuant to an agreement with the USEPA and MHI (USEPA, 1998b), MHI financed a removal action conducted by the USEPA in 1998 and 1999, whereby approximately 150,000 cy of PCB-containing residuals and sediments were excavated from the former Bryant Mill Pond and placed into the land-based disposal areas on site. In accordance with sampling procedures established in the *Final Work Plan - Interim Removal Action at Bryant Mill Pond* (Weston, 1998), approximately 92% of verification samples exhibited concentrations of PCB less than 1 mg/kg.

Excavated areas were backfilled with clean sand. The residuals and sediments placed into the disposal areas were subsequently graded, covered with clean fill, and vegetated with grass.

In January 2000, MHI voluntarily initiated an interim remedial measure (IRM) to close the disposal areas into which material from the former Bryant Mill Pond had been placed. Consistent with the IRM Draft Engineering Design Report (BBL, 1999), the disposal area berm was stabilized with approximately 2,700 linear feet of sheetpile installed where it borders Portage Creek. The MDEQ has indicated that installation of the sheetpile wall is consistent with what it expects will be the final remedy for the OU (Cornelius, 1999). Groundwater near the sheetpile wall is being extracted and treated during construction of the IRM. In addition, residuals were removed from between the sheetpile and Portage Creek and consolidated into the disposal areas. A final cover system consistent with Act 451, Part 115 requirements, including a flexible membrane liner (FML), will be constructed over the disposal areas. Construction of the IRM and the cover system are both expected to be completed by the end of 2000.

King Highway Landfill OU. Remedial response actions consistent with the KHL-OU ROD (USEPA, 1998a) began in 1996 and are anticipated to be completed in 2000. The remedial response actions included: berm stabilization by installation of an approximately 2000 foot-long sheetpile wall, cutting back the berm slope, and stabilization of the berm with riprap; and construction of a Type III landfill cover system. In addition, as part of the remedy, PCB-containing sediments identified in the river adjacent to the KHL-OU were removed during August and September 1999. Approximately 6,000 cy of sediments were excavated from the northern edge of the KHL-OU and disposed of in Cell 4 of the KHL-OU, while approximately 5,000 cy were removed from within the perimeter berm behind the sheetpile wall, and 1,000 cy were removed from in front of the sheetpile wall. After removing the materials in front of the sheetpile wall, approximately 700 linear feet of riprap (5 feet wide and 6 inches thick) was placed on top of geotextile along the sheetpile wall. The area behind the sheetpile wall was backfilled and revegetated along with the landfill. As part of residuals consolidation efforts, the KHL-OU received approximately 44,000 cy of residuals from the northern edge of the OU, the KSSS, and the Georgia-Pacific Mill Lagoons. Dike-stabilization and erosion-control measures were also implemented along the perimeter of the OU. Construction of an Act 451, Part 115, Type III landfill cap was completed in 2000. In addition, appropriate long-term institutional controls and maintenance are also part of the selected remedy. Closure of the KHL-OU was administered under the KHL-OU AOC (MDEQ, 2000a).

Willow Boulevard/A-Site OU. To stabilize the berm that separates the A-Site from the Kalamazoo River, a sheetpile was installed as a voluntary IRM. The sheetpile wall extends about 2000 feet along the Kalamazoo River and 150 feet along Davis Creek. This wall was installed to an elevation 2 feet above the 100-year flood elevation. As an additional IRM, PCB-containing sediments along the western bank of the Willow Boulevard Site and from the

Olmstead Creek confluence with the Kalamazoo River were excavated. From November 1999 to January 2000, approximately 7,000 cy of sediments were excavated and disposed of at the Willow Boulevard Site -- approximately 6,700 cy were excavated from the western bank, and 300 cy were removed from the Olmstead Creek confluence. The disposal area at the Willow Boulevard Site was graded and temporarily capped with a 6-inch-thick sand layer.

12th Street Landfill OU. Voluntary remedial response actions at the 12th Street Landfill OU conducted to date consist of the placement, in 1984, of 1 to 7 feet of topsoil over the landfill, and seeding to establish vegetation. The selected remedy for the OU, which was presented in the FFS Report (Geraghty & Miller, 1997), includes excavation, consolidation, and on-site containment of PCB-containing soils and residuals into the existing 200,000-cy landfill. A Proposed Plan was completed in July 1997 and presented for public comment. A ROD is awaited from MDEQ.

A voluntary IRM has been proposed for the 12th Street Landfill OU consistent with the ROD that is expected to be issued. For the IRM, PCB-containing soils and residuals in the adjacent wetlands would be removed and consolidated onto the landfill. Residuals in the Kalamazoo River that are visibly contiguous with the landfill would be removed from the river and placed on the landfill. Following consolidation of these materials and regrading of the landfill to promote proper drainage, a final cover system consistent with Act 451, Part 115 requirements would be constructed over the landfill. In addition, stabilization and erosion-control measures would be implemented along the river-side perimeter of the OU. Appropriate long-term institutional controls and maintenance would be implemented with the selected remedy.

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Inside Section 7 – Conceptual Site Model & RROs

Four key observations arise from an analysis of the information gathered and developed during the RI...

PCB available for transport or biological uptake is decreasing

- PCB levels in fish are declining.
- PCB levels in river water are declining.
- PCB levels in surface sediment are declining.
- These trends confirm that natural recovery processes are active in the Kalamazoo River and ~~will~~ continue to reduce exposure over time.

How much time?

Impoundments play a critical role in PCB fate and transport

- Impounded areas of the river slow water flow and trap sediment, which isolates PCB and decreases bioavailability.
- Drawdown of the Plainwell, Otsego, and Trowbridge impoundments released PCB downstream and created miles of eroding riverbanks that are adding PCB to the river.
- Lake Allegan is a large depositional area that is trapping and retaining the vast majority of PCB entering it.

Uncontrolled external sources of PCB continue to add PCB to the river

- Permitting, pollution control programs, and remediation of the OUs have led to significant decreases in discharges of PCB and other pollutants
- Uncontrolled sources – including upstream sources and the exposed sediment along the banks of the three MDNR-owned former impoundments – will hinder or slow the benefits of remedial actions and natural recovery.

Consumption of fish is driving exposure and potential risk

- Consumption of fish is driving exposure and risk for both human and ecological receptors.
- Land-based wildlife exposure pathways do not pose significant risks – to who??
- Swimming, boating, and ~~wading~~ do not pose significant risks.

worms, mice, etc. may play a role w eagles, owls, etc.

The primary remedial response objective is to reduce PCB concentrations in fish, Remedial alternatives must be developed to...

- ***reduce bioavailable PCB concentrations in the Kalamazoo River***
- ***control ongoing sources of PCB to the system***
- ***further reduce transport to Lake Michigan***

These remedial response objectives are addressed in detail in the Feasibility Study and Supplement to the Kalamazoo River RI/FS (BBL, 2000e).

7. Site Conceptual Model and RROs

7.1 What is the Site Conceptual Model?

The site conceptual model is the set of hypotheses resulting from the RI about the processes that determine PCB levels in Kalamazoo River fish. These hypotheses, or ideas, have emerged from the review of the RI data and more general scientific information about the transport and fate of PCB in aquatic ecosystems. The focus of the conceptual model centers around the accumulation of PCB in fish because this is the pathway leading to potential human health and ecological risks at the Site.

7.2 Importance of Fish PCB Levels

The most significant outcome of the ecological and human health risk assessments is the conclusion that fish consumption is the primary exposure pathway for receptors that may be at risk from PCB within media of the Kalamazoo River. Therefore, the key to reducing exposure and potential risks to important receptors (e.g., fish-eating birds, fish-eating wildlife, and humans) is to reduce PCB concentrations in the fish tissue consumed by these receptors. The greatest factor controlling PCB levels in fish is the bioavailability of PCB in surface sediments and the water column where fish and their prey come in contact with or ingest PCB. Compared to exposure via fish consumption, human exposure to PCB through direct contact with or ingestion of sediments, floodplain soils, or surface water at the Site does not pose significant risks.

Section Summary

The primary goal of the extensive investigations conducted over the past eight years was to gather enough information to evaluate the nature and extent of PCB contamination, the fate and transport of PCB, and the degree of risk posed by PCB in order to develop appropriate remedial response objectives for the Site. Collection and analysis of over 5,000 PCB samples confirmed that PCB are indeed the constituent of concern and revealed that PCB concentrations in all media (most importantly *fish tissue, surface sediment, and surface water)* have been steadily declining over time due to the natural recovery processes that are active in the Kalamazoo River.

Thus PCB concentrations in surface water are the lowest since at least the mid-1980s. Similarly, fish PCB levels have already dropped so low in some species (e.g., smallmouth bass) that consumption advisories can be removed or relaxed.

Despite the significant gains in risk reduction from natural recovery processes within the river, progress has been slowed by ongoing uncontrolled sources of PCB. The most significant of these is the erosion of PCB-containing material from what used to be submerged sediments in the three MDNR-owned former impoundments (Plainwell, Otsego, Trowbridge). When MDNR drained the impoundments in the 1970s, these former sediments were left above today's water line and now contribute 10 to 100 kg of PCBs to the river each year. If this source of PCBs were controlled, the rate and effectiveness of natural recovery would increase.

Lake Allegan is a very effective PCB sink, collecting a great majority of the PCB-containing sediment entering it, isolating the PCB in the sediment bed via the natural recovery process of burial, and rendering it unavailable for downstream transport or biological uptake. If the erosion of exposed sediments in the former impoundments were addressed, significantly less PCB would be entering Lake Allegan. Moreover, PCB concentrations in all fish, surface water, and surface sediments downstream of Plainwell would decline even more rapidly, thereby further reducing potential risks as the Site.

The remedial response objectives proposed for the Site are:

- Reduce PCB concentrations in fish;
- Reduce transport of PCB to Lake Michigan; and
- Control ongoing sources of PCB to the system.

Exposure reduction for humans and sensitive ecological receptors to PCB in fish is the central objective moving forward into the FS (i.e., the FS considers measures specifically designed to reduce PCB levels in fish as the key to reducing potential risks at the Site). This requires an understanding of the processes that govern PCB levels in fish to a degree that allows confident planning about how those PCB levels can be reduced in the future.

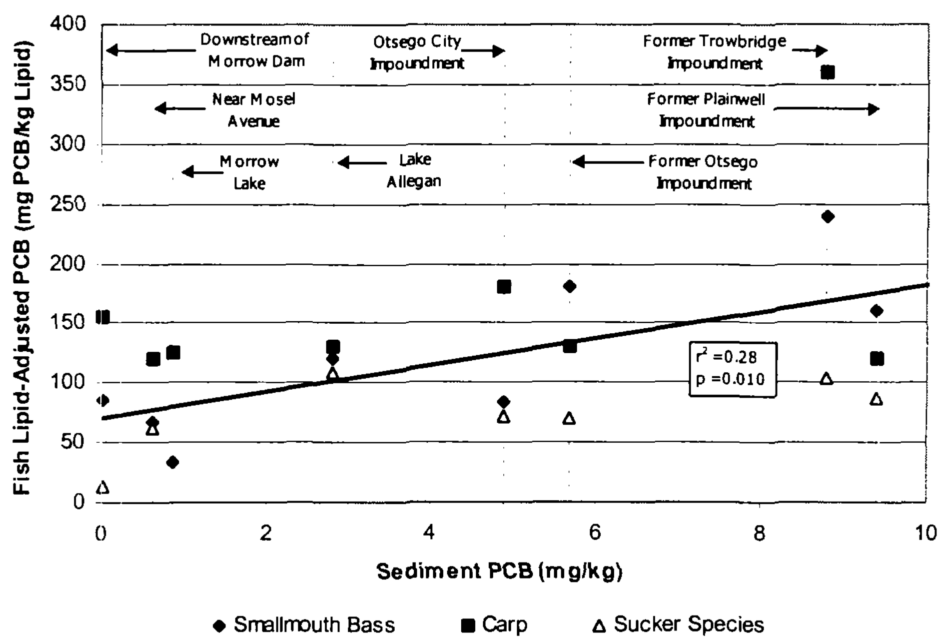
Recovery goals for eagles, mink?

In aquatic ecosystems such as the Kalamazoo River, PCB concentrations in surficial sediments regulate levels of PCB in fish. While this is readily apparent for bottom-feeding species such as carp, it also applies to species such as smallmouth bass that feed in the waters above the sediment. In relatively shallow systems like the Kalamazoo River, levels of PCB in fish, in food items, and in the water column will be closely related to PCB levels in surficial sediments. The relationship between surface sediment PCB levels within the areas where fish were collected in 1993 suggests a general relationship between fish PCB and surface sediment PCB. In the figure below, average lipid-adjusted fish PCB concentrations are related to dry-weight PCB concentrations in surface sediment samples. The data from the MDEQ's 1988 samples for Morrow Lake were used; additional Morrow Lake samples have been collected by the KRSG and are reported in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). It should be noted that the relationship between lipid-adjusted fish PCB and TOC-adjusted sediment PCB concentrations is weaker than that illustrated below for the dry-weight sediment PCB concentration when using the same data subset and averaging methods. This is an area that will be further explored in future work comparing 1999 fish PCB levels to results of ongoing analyses of approximately 400 additional sediment cores collected in 2000 (see *Supplement to the Kalamazoo River RI/FS* [BBL, 2000e]).

This wasn't true @ Fox River. Why is it here?

what does this mean?

Comparison of Lipid-Adjusted PCB Concentrations in Fish to Sediment PCB Concentration



So this shows that sediment surface PCB conc. is directly related to conc in fish? Is that right?

7.3 Regulation of PCB Levels in Bioavailable Zone Sediments

> - No PCB "hot spots" are present in the sediment.
> - PCB concentrations in fish, surface water, and surface sediment are declining as a result of natural attenuation processes.
> - Bioavailability of PCB also is declining due to natural attenuation processes, reducing risk to human and ecological receptors.

An understanding of the physical and chemical factors controlling the bioavailability of PCB in the Kalamazoo River has been developed by the data and information collected during the RI. The average thickness of a mixed layer of surface sediments generally corresponds to the zone of surface sediments in which PCB are bioavailable. The thickness of this "bioavailable zone" can range from as little as a few centimeters in systems having little mixing activity to as much as 10 centimeters in more highly mixed systems. Physical forces, such as those applied by flowing water and biological processes (e.g., as the burrowing, fish spawning, or other action of living organisms) control the thickness of the bioavailable zone.

This was not true @ Pine River

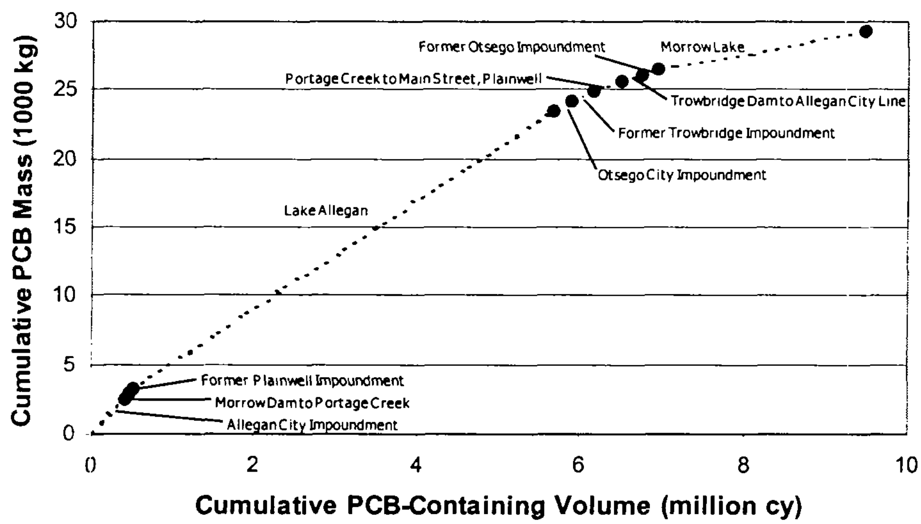
PCB levels in the bioavailable zone of sediment in the Kalamazoo River are determined by:

- The current distribution of PCB in the bioavailable zone;
- The supply, transport, erosion, and deposition of sediment; and
- External loading of PCB to the river.

In the Kalamazoo River today, the spatial distribution of PCB has been determined by the variations in the depositional character of sediments rather than distance from historical discharge sources. Areas that tend to favor the deposition of sediments having high fractions of silt, clay, and organic matter (TOC) have the highest dry-weight sediment PCB concentrations and largest associated PCB masses. Such areas are found throughout the river and are characterized by relatively slow-moving water. These areas are found near the shores in the more rapidly-flowing section of the river, towards the dam sills in the MDNR-owned former impoundments, and throughout much of Lake Allegan, Allegan City Impoundment, and Morrow Lake.

While the foregoing is a general model of PCB distribution, it should be noted that small-scale spatial variations in sediment PCB concentrations are relatively large. Differences between closely spaced samples have an average difference of roughly 100 percent. Within river sections where bank-to-bank (lateral) variations in surface sediment PCB concentrations are apparent, the variations are not significant when adjusted for TOC content. This suggests that, from a PCB bioavailability standpoint, the channel sediments are no less important than the near shore sediments.

The river contains no PCB "hot spots," relatively small, continuous areas of high PCB concentration sediments that contain a disproportionately large amount of PCB. The figure below presents cumulative estimates of PCB mass and associated sediment volume for sediments in the river channel (i.e., exposed sediment within the MDNR-owned former impoundments is not included).



I don't understand this figure.

As evident in this figure, the distributions of the total amounts of PCB and associated sediment lack a "knee" in the curve which would suggest a hot spot volume. Instead, the average PCB concentration in sediment, reflected visually by the slopes (PCB mass/sediment volume) within the figure, does not vary much from reach to reach along the river.

7.3.1 PCB Availability for Downstream Transport and Bioaccumulation is Decreasing

As previously demonstrated, there are statistically significant temporal trends in PCB levels in sediment, surface water, and fish when RI data are compared to historical data from the mid-1980s. PCB levels in fish and surface water have declined steadily since the mid-1980s, which strongly indicates that past source control and ongoing natural attenuation processes are decreasing the availability of PCB for biological exposure and downstream transport. These decreases have occurred despite continued PCB loading from external sources to the system, albeit at loading rates much lower than those of the 1970s.

Dams demolished in early 1970's -

As the physical availability of PCB at the sediment surface has decreased over the past two decades, the availability of PCB for desorption or advective particulate transport in the water column also has decreased. Analyses of surface water data from the mid-1980s, 1994, and 1999/2000 identify statistically significant decreases in PCB transport in the water column over this 15-year time period. Associated half times in surface water, the estimated time for concentrations to decrease by half, range from 4.4 to 6.3 years.

The natural attenuation of PCB levels in the bioavailable zone occurring in the Kalamazoo Rivers is also evident in the fish database, which includes data collected during the 1980s and RI field studies in 1993 and 1997. Between the mid-1980s and 1997, wet-weight PCB levels in smallmouth bass (< 16 inches), an important sport fish on the Kalamazoo River, have fallen from an average of 0.89 mg/kg to 0.10 mg/kg in Morrow Lake, from an average 1.8 mg/kg (1993) to 0.46 mg/kg in the former Plainwell Impoundment, and from an average 2.8 mg/kg to 0.50 mg/kg in Lake Allegan. Corresponding half times estimated from regression analyses of these data are 3.1, 2.7, and 4.6 years, respectively. PCB levels in carp fillet (≤ 22 inches) also are falling, but not as rapidly, with half times estimated for Morrow Lake, Plainwell, and Lake Allegan of 3.2, 11, and 6.3 years, respectively. Whole-body PCB levels in Lake Allegan monitored by the MDEQ from 1990 through 1999 have been declining with an associated half-time of 5.2 years.

These sediment, surface water, and fish data provide multiple lines of evidence that support the conclusion that natural attenuation processes are active in the Kalamazoo River and significantly decreasing PCB bioavailability and concentrations over time. Further, the natural processes that brought about such dramatic improvements in site conditions are expected to continue. Moreover, in the presence of additional source control, these natural processes would be expected to accelerate, thus hastening achievement of the central goal of reducing fish PCB concentrations and the associated potential risks to those receptors consuming fish from the Kalamazoo River.

Didn't happen @ Fire River

The reason for the diminishing bioavailability of PCB in the system is the combined effects of (1) clean sediment loading to the river, the (2) winnowing of fine-grained sediments with PCB from high energy areas, and their deposition and ultimate burial in low energy areas. These recognized physical processes of natural attenuation (USEPA, 1998) are the principal factors at work in the Kalamazoo River.

Sediment loading from the watershed drives the natural attenuation process. The magnitude of sediment loading to Lake Allegan is on the order of 30,000 metric tons per year. The mixing of that sediment with PCB-containing sediment at the surface of Lake Allegan results in a dilution of PCB concentrations in the mixed layer and burial of PCB-containing sediments. As shown by mass balance analysis of the mixed layer, the decline in fish PCB concentrations in Lake Allegan is proceeding according to rates and a pattern (i.e., exponential decay) explained by the mixing and burial of sediments in the lake by progressively cleaner sediments.

Existing impoundments are critical to the transport and fate of PCB because they act as sediment traps and tend to sequester PCB in the sediment bed, effectively isolating them from potential human and ecological exposure. Lake Allegan is the largest impoundment on the Kalamazoo River, covering approximately 1,650 acres. Impoundment of the lake's waters slows river flow and creates a low-energy environment that acts as a highly efficient sediment trap. Based on the 1993 RI data, approximately 20,400 kg of PCB are contained in 5.14 million cy of sediment in the river channel (i.e., excluding the exposed former sediments) from the Allegan City Dam to the Lake Allegan Dam. Lake Allegan contains approximately 70% of the PCB-containing sediment within the river channel. An additional 2,800 kg and 2,500 kg are estimated to be contained in the sediments of Morrow Lake and the Allegan City Impoundment, respectively. When added to Lake Allegan, 88% of the total mass of PCB in the submerged river sediment is retained within these three impoundments.

The bed of Lake Allegan as a whole appears to be resistant to the potential effects of very high (and rare) river flow events given its large cross sectional area. The preliminary erodibility analysis suggests that, except for Lake Allegan, the other current and former impoundment sections downstream of Morrow Lake are not expected to accumulate substantial amounts of additional fine-grained sediment. Although deposition of coarser sediments may occur within certain reaches, winnowing of fine-grained sediment from the bed and downstream transport to depositional areas appears to be the mechanism determining PCB levels in the faster-flowing sections of the Kalamazoo River.

A significant factor to be considered in evaluating potential remedial alternatives is the impact of external PCB sources. Within the Kalamazoo River there are uncontrolled sources of PCB which ultimately will control the levels of PCB in surficial sediment and fish unless their loading is reduced. External sources of PCB, most notably the eroding banks of the three MDNR-owned former impoundments, will sustain PCB in fish above levels deemed acceptable by regulatory agencies if not controlled. The nature of industrial development in the watershed and empirical evidence suggest that the other external sources also may still be contributing PCB to the river. Chromatographic evidence shows that PCB mixtures not associated with former paper recycling operations (e.g., Aroclor 1254-like PCB) contribute significantly to PCB concentrations in sediment and fish between Morrow Lake and Lake Michigan. PCB continue to move into the Site from upstream sources. For example, approximately 2,800 kg of PCB are contained in Morrow Lake sediments, and PCB levels measured in Morrow Lake surface water and fish exceed MDEQ surface water quality standard and health criteria, respectively. Thus, a remedy for the Kalamazoo

How much of a source is Morrow lake?

River must recognize that upstream sources will continue supplying PCB to the downstream portions of the river if not controlled.

The largest uncontrolled external source of PCB to the Kalamazoo River is the exposed former sediments of the three MDNR-owned former impoundments. The former Plainwell, Otsego, and Trowbridge impoundments hold 2.8 million cy of former sediments containing approximately 24,500 kg of PCB at concentrations higher than levels presently detected within submerged sediments of the river. These former sediments have not been submerged under the Kalamazoo River since the mid-1970s when the MDNR drew the impounded water down 5 to 10 feet to present levels. Prior to drawdown, these impoundments were quiescent depositional basins occupying approximately 1,100 acres. This drawdown resulted in approximately 510 acres of exposed former sediments released and redistributed downstream approximately 1.1 million cy of PCB-containing sediment that were once underlying the present channel in these areas. This dramatic change in river geometry created approximately 10 miles of new river channel running through the formerly submerged sediments within the three former impoundments. The banks of the new channel, which are 3 to 4 feet high in many areas, remain susceptible to erosional forces that transport PCB into the river.

Simple mass balance calculations show that PCB levels in surficial sediment and fish PCB are highly sensitive to PCB loading from the former impoundment banks. The expected magnitude of bank erosion PCB losses (10 to 100 kg/yr) from all three impoundments represents 25 to 250 percent of the annual flux of PCB for the Kalamazoo River. Estimates of bank loss from survey measurements made in 1993 and 1999 were used to refine an estimate of PCB loading from the banks. These data and calculations are presented in the accompanying *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

At Pine 0-2" was [actually 0-6"] least contaminated.

Another way of examining the importance of this magnitude of PCB loading is to consider the quantity of PCB within the bioavailable zone of various sections of the river. The table below presents the estimated mass of PCB in the 0- to 2-inch layer of submerged sediment based upon 1993/1994 sediment cores for each of the reaches downstream of the MDNR-owned former impoundments.

River Section	PCB Mass (kg) 0-2 inch
Former Plainwell Impoundment	32
Otsego City Impoundment	73
Former Otsego Impoundment	68
Former Trowbridge Impoundment	72
Trowbridge Dam to Allegan City Line	24
Allegan City Impoundment	97
Lake Allegan	1,000

The magnitude of bank PCB loading (10 to 100 kg/yr) is comparable to the magnitude of PCB mass in the top two inches of sediment for all sections but Lake Allegan, suggesting a relatively high degree of potential influence on the levels of bioavailable PCB in river sections upstream of Lake Allegan. The continued loading of PCB from the banks of MDNR's former Plainwell Impoundment may be a reason that PCB levels in fish collected there appear to be declining at slower rates than in Morrow Lake or Lake Allegan. The comparable magnitudes of annual bank loading of PCB, annual PCB transport in the Kalamazoo River and the quantity of PCB in bioavailable zone sediment indicate the ability of bank loading of PCB to sustain PCB concentrations in fish at existing levels upstream of Lake Allegan. As the mass of PCB in the bioavailable zone decreases over time due to the physical processes at work in the system, the influence of bank loading at these rates would increase. Assessment of the processes qualitatively in Section 5 indicates that over the longer term, even PCB levels in Lake Allegan fish could be sustained above acceptable levels by PCB continued loading from the eroding former impoundment banks.

How? Because contam. sediment deposits in top 2" of existing sediment? or, erosion creates PCB avail in water column?

> - Erosion of the banks in the three former impoundments is the largest uncontrolled source of PCB to the river.
> - Uncontrolled point and non-point sources of PCB related to industrial activities may also be significant.

Potential external sources like point and non-point sources from industrial and urban areas likely still persist, albeit at much lower levels than in the past. Indications of significant historical industrial PCB sources other than from paper recycling includes:

- Observations of significant concentrations of Aroclor 1254-derived PCB in the sediment (e.g., just downstream of the Auto Ion Superfund Site, Morrow Lake, Portage Creek near Axtel Creek, others);

- Assessment of the composition of PCB in fish indicating that roughly one-half of the PCB in fish today originates from sources other than paper recycling (see Section 4.6); and

- Other information documenting historical discharges of PCB (e.g., PCB discharge measurements, PCB purchase records).

The presence of current uncontrolled discharges of PCB to the Kalamazoo River is an important subject of uncertainty pertaining to the ultimate fate and transport of PCB and the response of the river media to remedial actions. Where evidence of continued discharge of PCB has been investigated, the findings suggest that a comprehensive investigation by the State would indeed uncover remaining PCB sources to the river. Furthermore, it is probable that historical "reservoirs" of PCB exist and actively discharge during high flow events. These areas include stormwater drainageways and exposed soils in scrap yards (see Appendix N) or other industrial areas that accumulated PCB and other wastes prior to the stringent regulations of today. Voluntary response actions at the KRSG Mills, OUs, and related areas have reduced the actual or potential loading of PCB to the river system.

If the loading of PCB to sediments continues at current rates, there would be no significant benefit to reducing Lake Allegan fish PCB levels by actively controlling upstream sediment. The effects of physical processes of natural attenuation can be offset by PCB loading of the magnitude currently estimated from the banks of the MDNR-owned former impoundments. PCB loading from the banks eventually would sustain a relatively constant and unacceptable level of PCB in surface sediments if such loading did not diminish over time.

I don't understand — what's their point? It sounds to me like they're saying the impounded sediments need to be controlled.

7.4 Summary

> - PCB concentrations in all media are declining over time.
> - Erosion of the banks of the three former impoundments is a significant uncontrolled source of PCB to the river.
> - Lake Allegan is a highly effective sediment trap, burying PCB and making it unavailable for downstream transport or biological uptake.

The conceptual model of the Kalamazoo River indicates continuing reduction in the bioavailability of PCB in the system. The nature and extent of PCB in the Kalamazoo River, and associated fate and transport mechanisms, are well defined by the existing data and observations and analyses derived from that data. Fish in the Kalamazoo River show continuing declines of PCB concentrations, and surface water reflects a similar trend over time. The most significant active sources of

what about surficial sediment? Their whole argument is that its the conc in 0-2" of sediment that controls levels in fish.

PCB to the Kalamazoo River system (and ultimately fish) are the eroding banks of the exposed sediments within the three former impoundments.

I know Doyle H. thinks there is significant sediment scouring from Lake A downstream.

While the former impoundments continue to act as a source of PCB to the river, Lake Allegan continues to act as a sediment trap, and the PCB in its sediment bed is not readily available for transport. So while large PCB reserves exist in each, only the banks of the former impoundments threaten to continue indefinitely as a source of bioavailable PCB. If this source was mitigated, sediment collecting in Lake Allegan would be cleaner and would more readily dilute, bury, and isolate the existing PCB-containing sediment, in turn reducing exposure of PCB to fish.

I would probably have to disagree w/ this conclusion.

7.5 Remedial Response Objectives

> - RROs designed to protect human health and the environment will be fully assessed in the FS.
> - Reduction of PCB fish tissue concentrations, reduction of PCB transport to Lake Michigan, and reduction of ongoing sources of PCB are the goals for Site remediation.

This section identifies the remedial response objectives (RROs) developed for the Site based on the findings of the RI and the risk assessments, as well as USEPA guidance and experience at similar sites. As stated in USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA, 1988), remedial objectives consist of media-specific or OU-specific goals for protecting human health and the environment and are intended to fulfill potential federal and state applicable or relevant and appropriate requirements (ARARs) and "to be considered" criteria (TBCs). Further, the guidance indicates that constituents of concern, exposure pathways and receptors, and preliminary remediation goals should be reflected in the RROs. The RROs proposed for this Site, where PCB are the primary constituent of concern, are as follows:

Primary RRO:

- Reduce PCB concentrations in Kalamazoo River fish tissue to acceptable levels in terms of human and ecological risk.

Ancillary RROs:

- Reduce water-column transport of dissolved or particle-bound PCB to Lake Michigan; and

- Reduce PCB loading to the Kalamazoo River.

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Section 5

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

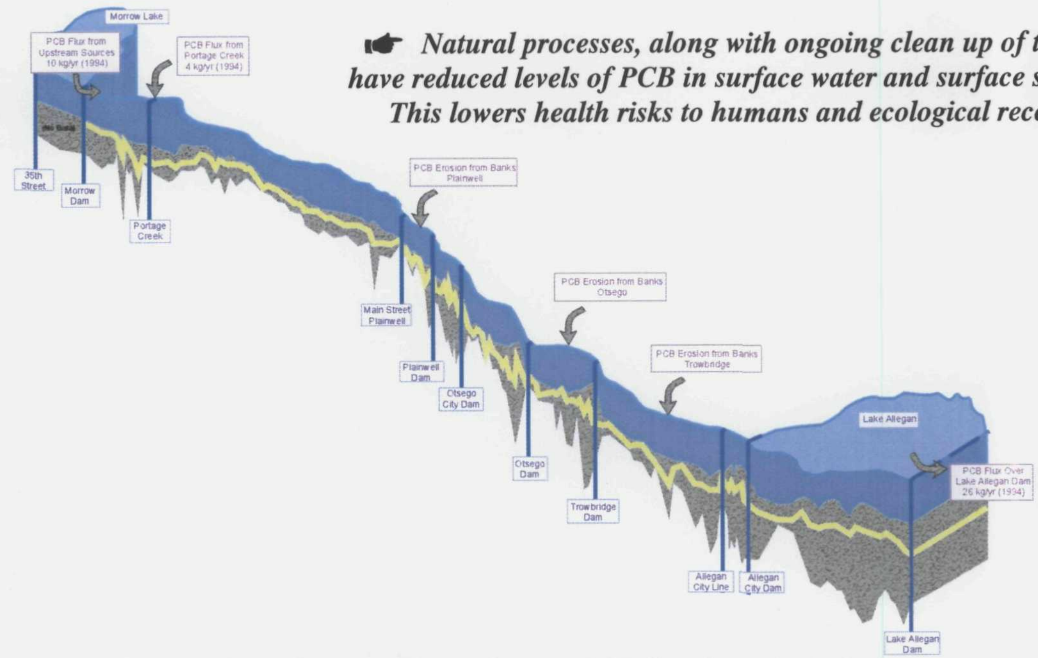
Section 5
Fate and Transport

Inside Section 1 – Introduction
Inside Section 2 – Site Investigations
Inside Section 3 – Physical Characteristics of the Site
Inside Section 4 – Nature and Extent of Contamination in the Kalamazoo River System

Inside Section 5 – PCB Fate and Transport

Inside Section 6 – Risk Assessment
Inside Section 7 – Site Conceptual Model and RROs

Natural processes, along with ongoing clean up of the OUs, have reduced levels of PCB in surface water and surface sediment. This lowers health risks to humans and ecological receptors.



Model of the Kalamazoo River, showing PCB flux throughout the Site.
(Vertical scale modified for illustrative purposes, river width is not to scale. Length of river is to scale, 1 inch = 12 miles)

Mechanisms of PCB transport

- Erosion of riverbanks in the three MDNR-owned former impoundments.
- Desorption, diffusion, and advective transport of PCB from the sediment bed into the water column.
- Resuspension of PCB adsorbed to particles.
- Discharges from industrial and municipal sources.

Trend analyses

- PCB concentrations in surface sediment in impounded areas are being reduced by half every 6 to 14 years.
- PCB concentrations in surface water are being reduced by half every 4 to 5 years.
- PCB concentrations in fish are being reduced by half every 3 to 15 years.

Transport of PCB is declining

Natural processes (such as mixing and burial of PCB-containing sediments with progressively cleaner sediments) have contributed substantially to a steady decline in the amount of bioavailable PCB over the past two decades, as well as a decrease in PCB transported downstream to Lake Michigan.

5. PCB Fate and Transport

This section describes processes governing the transport (i.e., movement) and long-term fate of PCB in the Kalamazoo River, and evaluates their significance empirically and through application of deterministic mathematical equations. The results of these studies are supported by the fate and transport model which appears in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

> **Section Summary**
>
> Chemical properties influence how PCB move within the environment (transport) and where they end up (fate). For the Kalamazoo River system, attachment (or adsorption) of PCB to solid materials such as sediment is one of the most critical considerations. The current distribution of PCB with the river system provides a good clue as to how and where PCB will ultimately be deposited. For example, the vast majority of PCB and associated sediment have settled within the river's existing impoundments.
>
> RI studies estimated PCB movement within the Kalamazoo River system, assessed the fate of PCB in the river, and analyzed PCB fate and transport.
>
> Highlights of findings include:
>
> - Data indicate that transport and bioavailability of PCB in the Kalamazoo River have been declining steadily over the past two decades. This finding is based on studies of rates of change in sediment, surface water, and fish.
> - Natural processes (also called "natural recovery" or "natural attenuation") appear to be the major reason for this decline. Data indicate that physical processes are reducing the bioavailability of PCB over time.
> - These findings of declining PCB concentrations are supported by both trend analyses of PCB data and simple desktop systems analyses.

The chemical properties of PCB (e.g., solubility, volatility, affinity to nonaqueous phases such as solids and organic particles, biodegradability) influence the mode of transport and the ultimate fate of PCB in the environment (see Appendix L for detailed discussion of these processes). These characteristics vary greatly among the 209 PCB congeners, resulting in different behavior between the lighter, less-chlorinated PCB molecules and the heavier, more-chlorinated PCB molecules. Due to the generally low solubility and consequent high affinity of PCB for adsorption to natural solids (particularly organic matter fractions of those solids), the transport and fate of PCB in river systems is closely tied to the transport and fate of solids. This chemical affinity for solids makes sediment the ultimate sink for PCB and, to a more limited extent, the reservoir supplying PCB to the water column and biota within the aquatic ecosystem.

The ultimate long-term fate of PCB in the Kalamazoo River system is evident from the current distribution of PCB mass. That is, a vast majority of PCB mass and an extremely large volume of associated sediment have settled out in impoundments within the system. The current distribution of PCB concentrations in sediment lacks the significant spatial gradients that give rise to "hot spots," areas where relatively small volumes of sediment contain a disproportionately high mass of PCB. Figure 4-14 presents the distribution of total PCB mass, both in the river channel and in the exposed sediments in the former impoundments. This figure indicates the primary location of deposition is Lake Allegan, where an estimated 38% of the total PCB mass in exposed and submerged sediments is located. Excluding the sediment in the former impoundments, Lake Allegan represents approximately 70% of the

PCB mass in currently submerged sediment. The MDNR-owned former impoundments were significant historical depositional environments during the time that they were impounded by dams, as evident in the fact that nearly 48% of the river's PCB mass currently resides at these locations (approximately 46% in exposed sediment, 2% in existing channel sediment). Of the remaining 14% within the system, 6% of the total PCB mass is deposited in the Otsego City and Allegan City impoundments, 5% is found in Morrow Lake, and 3% is distributed throughout other stretches of the river. These data demonstrate the importance of the impounded areas as repositories for PCB-containing sediments.

5.1 PCB Transport within the Kalamazoo River System

> ➢ PCB in the Kalamazoo River sediment have accumulated where fine-grained, organic sediment has accumulated – in impounded areas.

PCB transport within the Kalamazoo River system is governed by advective transport by the water column. The amount of PCB transported annually is affected not only by hydrologic variables, but also by the spatial distribution and nature of PCB sources to the water column. Prior to the restrictions placed on the use and disposal of PCB in the 1970s, and the resulting reductions in point source discharges, the water column served as a significant source of PCB to the sediment, conveying PCB-containing material downstream and depositing it with sediments primarily in low-energy areas. Since then, characteristics of PCB transport have shifted emphasis to resupply from the sediment bed to the water column in many areas of the river. In Lake Allegan, sediments appear to continue to be a net sink for PCB transported from upstream, as shown by recent water column data.

Although overall loadings are much lower since reduction of point source loads, external sources (including the river bank deposits in the MDNR-owned impoundments, former or current industrial facilities, POTWs, and inactive hazardous waste sites) have continued to contribute PCB to the Kalamazoo River upstream of the Lake Allegan Dam. If not for the ongoing addition of PCB from the former impoundment banks, PCB would be buried and removed from the biologically active near-surface zone of sediments at a greater rate. These factors, in addition to the influence of impoundments in the downstream portion of the river that tend to act as sediment traps for suspended sediment (e.g., Lake Allegan), dictate the current and future distribution of PCB in the Kalamazoo River.

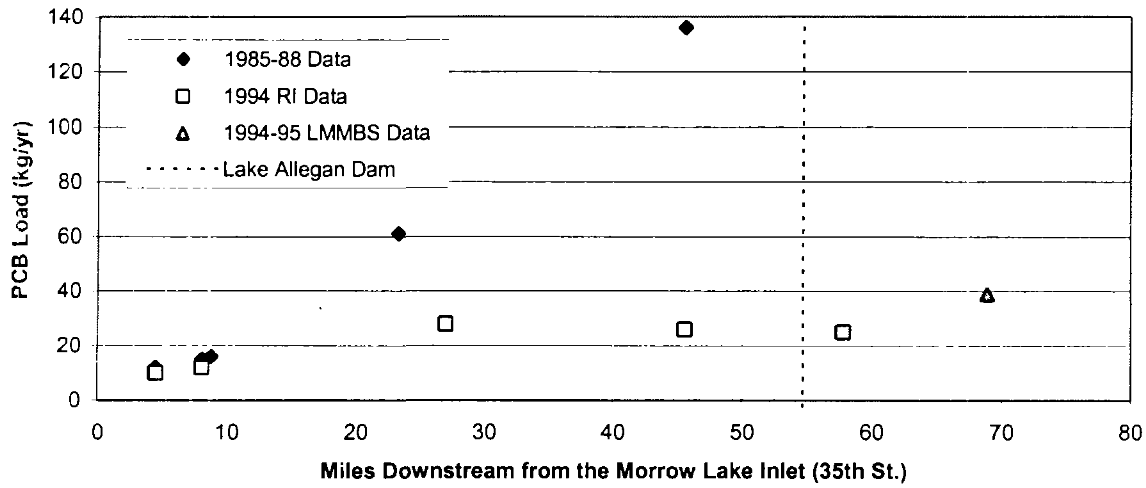
5.1.1 Estimates of Annual PCB Transport in the Kalamazoo River

> - PCB transport in the Kalamazoo River is best described by a "flow-stratified" method. This method weighs every day events more heavily than sporadic storm events.
> - Transport of PCB in the river has decreased since the 1980s.

PCB transport at various sampling locations in the Kalamazoo River was quantified in terms of annual mass loads. Mass loads are calculated as the product of PCB concentration and the flow rate which carries it; these estimates are then annualized for ease of comparison. Load estimation methods can vary widely in the way they represent instantaneous data as average annual conditions. Based on the [redacted], mean annual PCB load estimates for each sampling location were calculated using five different averaging techniques (Table 5-1), which are described in detail in *Draft Technical Memorandum 16* (BBL, 1995a). In that document, the flow-stratified method was determined to be the most robust method and the method most appropriately applied to Kalamazoo River data. The flow-stratified method weighs observed PCB concentrations by the annual frequency in which they are observed. This method eliminates bias of observed data which occur in flows that rarely occur, while more heavily factoring observed concentrations in flows occur frequently. This method was applied consistently to available surface water data. Calculations and results of PCB load estimates for the 1994 data and MDNR data collected in the 1980s are provided in Tables 5-2 and 5-3, respectively. PCB loading estimates based on surface water data collected from March through July 2000 are presented and compared to other loading estimates in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

PCB load estimates based on available comparative data show that PCB transport in the Kalamazoo River has decreased since the 1980s. Estimated annual PCB loads are presented by river mile in the graph below. In the mid-1980s, PCB load estimates based on MDNR data show a substantial downstream gradient, increasing from approximately 12 kg/yr at River Street to 61 kg/yr at Plainwell, and then to 140 kg/yr at M-222 in the Allegan City Impoundment. Comparatively, PCB loads in 1994, while similar to the 1980s at River Street (10 kg/yr), increased only to 28 kg/yr at Plainwell, and remained relatively constant in the downstream direction (26 kg/yr at M-222 in Allegan, and 25 kg/yr at M-89 downstream of Allegan Dam). The 1994 data show a significant decrease in PCB loads downstream of Kalamazoo since the 1980s, as well as a much lower contribution of PCB to the water in the intermediate reaches between River Street and Allegan City Impoundment. The LMMBS data collected in 1994 and 1995 yields an annual load of 38 kg/yr at 58th Street near New Richmond, which is in the same general range of the PCB load estimates produced by the 1994 RI data.

Estimated Annual PCB Load in the Kalamazoo River



NOTES:
The calculation of the estimated PCB load used a flow-stratified method,

The estimated PCB load for the mid-1980s (see Table 5-3) for the Kalamazoo River downstream of Lake Allegan (140 kg/yr) is consistent with the range of those estimated by other investigators. For example, estimates of annual PCB transport from the Kalamazoo River to Lake Michigan include 125 kg/yr (Hesse, 1973; MWRC, 1972, 1973), 47 to 200 kg/yr (Horvath, 1984), 77 to 140 kg/yr (MDNR, 1987), 26 to 100 kg/yr (Marti, 1990), and 110 kg/yr (NWF and CIELP, 1991). The overall downward trend of PCB transport over time is consistent with reductions in PCB availability from natural processes and reductions in loading of PCB to the river from external sources including those associated with the mills and OUs.

5.1.2 External Sources of PCB

> ➢ The largest uncontrolled external source of PCB to the Kalamazoo River within the NPL Site appears to be erosion from the banks of the former Plainwell, Otsego, and Trowbridge impoundments.

External PCB sources are [illegible] from outside of the Kalamazoo River [illegible] than the sediment bed. The existing riverbanks within the three MDNR-owned former impoundments act as PCB sources via bank erosion and soil slumping into the channel. Loading of PCB from the OUs and other KRSG facilities, and the potential for loading from these areas, has been greatly reduced through various response actions. Further response activities are expected to virtually eliminate contributions from these areas. Other industrial sources and POTW discharges of PCB both upstream and within the Site have affected the spatial distribution of PCB and, therefore, PCB transport characteristics. Evaluation of available analytical PCB data provides direct evidence of PCB sources other than paper recycling facilities, and of the significant relative impact of those other sources on total PCB concentrations in fish tissue (see Appendix K). The precise amount of PCB loaded to the system from these sources currently is unknown, however, their potential significance relative to current transport remains a factor. More details regarding sources of PCB are provided in Appendix K.

Erosion of the exposed sediment within the MDNR-owned former impoundments appears to be the single greatest active external source of PCB to the Kalamazoo River. Upon MDNR's permanent drawdown of the impoundments to their sill levels in the early 1970s, the Kalamazoo River quickly carved a new channel into the soft sediments behind the dams, leaving steep banks of exposed sediment as the new stream banks. These banks are susceptible to slumping and erosion during and after high-flow events as the river flows through the former sediments and PCB mass contained within those former sediments. [redacted] As illustrated previously (see Section 4.2.2), intuitively reasonable estimate of bank loss in these areas yield a magnitude of annual PCB loading of 10 to 100 kg to the river. Quantitative estimates of bank erosion based upon survey measurements made in 1993 and 1999, and a refined estimate of PCB loading are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). Given the erodible nature of the bank deposits and the flat and densely vegetated nature of the remainder of the areas of exposed sediment, bank erosion is expected to be the predominant pathway for PCB loading from these areas. Indeed, during flooding these larger surface areas may be sinks for sediments and PCB from the river. It should be noted, however, that some portion of the PCB loaded from erosion of the banks is retained within the sediment bed of the former impoundments. The percentage of PCB transport in the Kalamazoo River attributable to erosion of banks in the former impoundments has been estimated through calibration of a mathematical model of PCB transport (see the *Supplement to the Kalamazoo River RI/FS* [BBL, 2000e]). As reductions through ongoing cleanup efforts and natural attenuation processes continue to reduce the availability of PCB for transport, the impoundment banks will constitute a larger and larger percentage of PCB load since the source is virtually unlimited for years to come.

Portage Creek also has been a source of PCB to the Kalamazoo River. Estimates of PCB loading from Portage Creek were made using samples collected during 1994 (and in 1998 [redacted]). As with the river calculations, stratified flow estimation methods were used. Results are presented in Table 5-1, illustrated on Figure 5-1, and explained in greater detail in *Draft Technical Memorandum 16* (BBL, 1995a). Estimated transport for 1994 was 4.2 kg/yr.

5.1.3 Internal Sources of PCB Transport

> ➢ The internal source of PCB is the surface sediment from which PCB dissolve or are resuspended into the water.

In aquatic systems such as the Kalamazoo River, [redacted] whether through direct contact between aquatic organisms and the sediment bed, or potentially through the food chain relationships of benthic organisms and fish. Internal PCB sources that are potentially bioavailable to the aquatic food web within the Kalamazoo River channel between Morrow Lake and Lake Allegan are limited to [redacted] Other than advection of PCB from upstream sources external to the NPL Site (e.g., Morrow Lake and upstream; see Section 4.5.1), PCB in surface water are derived from the sediment bed either through desorption, diffusion of advective transport from the sediment; or resuspension of PCB adsorbed to particulate matter (i.e., TSS).

5.2 Empirical Assessment of the Fate of PCB in the Kalamazoo River

> ➢ Data indicate that levels of PCB in the Kalamazoo River have been declining steadily over the past two decades.
>
> ➢ Natural attenuation processes reduce the concentration, toxicity, or bioavailability of contaminants. The burial and isolation of PCB by progressively cleaner sediment is an important part of the recovery of the Kalamazoo River.

The RI has produced several types of data that combine to identify the fate of PCB in the Kalamazoo River system and quantify associated rates of change in sediment, surface water, and fish. As noted below, data from each of these media indicate that the transport and bioavailability of PCB in the Kalamazoo River have been [redacted] over the past two decades. Natural attenuation processes in river systems such as the Kalamazoo are those chemical, physical, and biological processes that reduce the concentration, toxicity, or bioavailability of chemicals in sediments. The major mechanism of this decline appears to be natural attenuation via physical processes, which are reducing availability of PCB from the sediment bed as progressively cleaner sediments delivered by the watershed mix with and gradually bury PCB over time. To a much lesser extent than physical processes, evidence of PCB dechlorination, which reduces PCB toxicity and bioavailability, has been observed in sediment from the Kalamazoo River. A discussion of dechlorination is provided in [redacted]

Several methods have been applied to [redacted] within the system, [redacted] and the [redacted] A significant amount of historical and recent data provide multiple lines of evidence of ongoing natural attenuation within the Kalamazoo River and support the quantification of attenuation rates, including:

- Geochronological sediment data. Finely sectioned cores demonstrate continually decreasing rates of PCB deposition in the Kalamazoo River over the past two decades.

- Surface water PCB data for 1985-1988, 1994, and 1999-2000. Data show a substantial decrease in PCB concentrations in surface water since the mid-1980s. Surface water data collected from March through July 2000 are compared to projected trends in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

- Fish tissue PCB data from collections by the MDNR in the 1980s and 1990s, and those related to this RI/FS in 1993 and 1997. Fish PCB concentrations have declined over time to such an extent that, [redacted]. Fish data collected in 1999 are compared to projected trends and to fish consumption advisory criteria in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

Methods employed to estimate rates of natural attenuation in the Kalamazoo River from these data include:

- Graphical analysis of PCB levels over time;

- Assessment of geochronological sediment data to approximate the decline of PCB transport via suspended sediment; and

- Statistical regression analysis of PCB data to estimate half-times for PCB concentration in each medium (i.e., the time it takes, on average, for a given concentration to decrease by half), and the confidence intervals for these half-times.

5.2.1 Sediment Trend Analysis

> ➢ The surface sediment PCB concentration in the Allegan City Impoundment decreases by half every 6.5 to 14 years.

To develop chronologies of PCB deposition and to quantify the rate of natural attenuation in the river, sediment cores were collected from Allegan City Impoundment and Kalamazoo Lake (near Lake Michigan), in 1993 and 1995 and analyzed for ^{137}Cs, ^{7}Be, and PCB. The results of ^{137}Cs and ^{7}Be analyses are used to determine the age of sediment strata, which can be translated into a geochronological history of the sediment bed. These methods have been used successfully to assess deposition rates and changes in sediment contaminant transport in other aquatic ecosystems (Pennington et al., 1973; Voskov et al., 1991; Bopp et al., 1993; Albrecht et al., 1998, Van Metre et al., 1998). [redacted] BBL, 1994d).

Areas sampled were not selected based upon their spatial representations of river sediment, but instead for this potential to yield interpretable ^{137}Cs and PCB deposition chronologies. To increase the likelihood of finding cores yielding interpretable radionuclide profiles, these cores were collected from areas that appeared to favor relatively high and uniform rates of fine-grained sediment deposition. The areas selected for sampling are expected to be atypical with respect to sediment composition and vertical distribution of PCB in other less-depositional areas. For example, sediment grain-size is expected to be finer and the PCB-containing layer to be thicker in these areas than most of the river. As noted above, this sampling design is not intended to characterize the spatial distribution in the river; rather, these areas are selected based upon apparent ability to essentially sample the historical transport of sediment-borne PCB.

Regression analyses were performed using data from the five cores which produced usable ^{137}Cs profiles for sediment dating: AL1-2 and AL2-4 from Allegan City Impoundment, and KL2-1, KL2-2, and KL2-4 from Kalamazoo Lake. [redacted]. Consistent with the application of first-order kinetics, the log-transformed PCB concentrations were employed in these regressions. The regression trend lines (and confidence limits) are presented with the observed data for Allegan City Impoundment and Kalamazoo Lake (Figures 5-2 and 5-3), respectively. Results of the regressions for the five cores are summarized below.

Location	Core	Earliest Sediment Interval Used (Year)	r^2 ($p<0.01$)	Half-Time (Years)	95% Confidence Interval	
					Lower	Upper
Allegan City Impoundment	AL1-2	1975	0.52	6.5	4.0	16
	AL2-4	1975	0.78	14	10	21
Kalamazoo Lake	KL2-1	1977	0.86	3.5	2.8	4.9
	KL2-2	1976	0.82	4.8	3.6	7.1
	KL2-4	1977	0.76	4.8	3.7	7.1

Based on the two cores from the Allegan City Impoundment, estimated half-times for surface sediment PCB concentrations were 6.5 years and 14 years. For Kalamazoo Lake, the estimated half-times based on three cores were consistent, ranging from 3.5 to 4.8 years.

[redacted]ected from throughout the Kalamazoo River [redacted]l analysis. These cores were collected from each of the eight former and existing impoundments from Morrow Lake to Kalamazoo Lake. Although the PCB data from these cores have not been received at the time of this report, they will provide a measure of spatial variability of sediment and PCB deposition and associated natural process rates, as well as an updated snapshot of the current conditions in the river.

5.2.2 Surface Water Trend Analysis

> - Comparison of historical data show that PCB concentrations in surface water are declining.
> - PCB concentrations downstream of Plainwell are decreasing by half every 6 years.

Surface water PCB data for the Kalamazoo River are available dating back to the mid-1980s. Since that time, extensive sampling has occurred in 1994 (as part of the 1994 RI) and more recently in 1999 and 2000 (CDM 1999-2000 surface water sampling). To assess temporal trends in the surface water PCB concentration, an evaluation of the comparability of the data from different sources and time periods was conducted. This evaluation: 1) showed that the whole water PCB data between data sets can indeed be used for temporal trend analysis; and 2) ruled out incompatibly due to differences in detection limits between sampling events, differences in flow conditions between sampling events, or differences due to seasonal variability among sampling events.

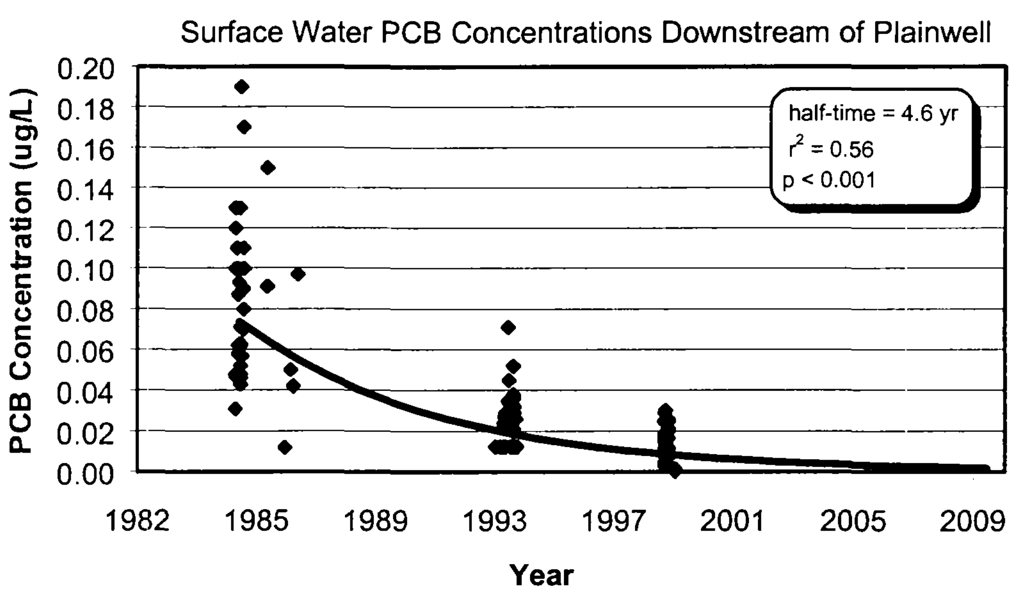
[redacted]apparent difference in the detection limits utilized [redacted]ed. Observation of the historical data (provided in the DCS) shows that there were no reported non-detections at the Allegan City Impoundment and Plainwell locations. Therefore, by focusing the temporal trend analysis on the data available for these locations, any possible bias introduced by the variation in detection limits can be removed.

To check the assumption that temporal trends of PCB concentration were not affected by variability in flow rates corresponding to the PCB samples, the relationship between PCB concentrations and flow were graphically evaluated for the Plainwell and M-222 locations. These graphs are presented on Figure 5-4. Although sampling during 1985-1988 focused more on low-flow conditions than high-flow conditions, the graphs clearly show PCB concentrations at similar flows exhibit little overlap for the two time periods at Plainwell, and no overlap at the M-222 location.

The effect of seasonal variability on PCB concentration was assessed by comparing the data sets by month of collection. As noted above, the historical data was collected primarily in summer months, therefore any potential discrepancy introduced by season was eliminated by comparing only like months (i.e., May to July). Results of a statistical analysis showed a clear statistically significant difference between the 1980s PCB concentration data, and both the 1994 RI and the 1999-2000 CDM data (see Section 4.5.1).

Figure 4-23 compares the 1999/2000 CDM PCB data and 1994 RI PCB data to historical MDNR PCB data. Average PCB concentrations in the Kalamazoo River downstream of D Avenue were approximately two to five times lower in 1994 and 2000 than those observed between 1985 and 1988 at similar locations. Between River Street and D Avenue there is little apparent difference between the historical and more recent average PCB concentrations; however, PCB concentrations at these locations were already very low.

Due to the low frequency of PCB detections in the Kalamazoo River upstream of Portage Creek, trend analysis was performed using only data downstream of the confluence. Three trends were evaluated: using data from Plainwell and all downstream locations to assess PCB trends throughout the entire area (see figure below); using site-specific data collected above Plainwell Dam; and using site-specific data collected below Allegan City Dam (at Route M-222). The latter two locations had sufficient historical and recent data for a statistical comparison. In the case of the Plainwell data, the RI samples were collected at the Farmer Street bridge just downstream of Otsego City Dam and historical data were pooled for Farmer Street, Plainwell Dam, and 10th Street (in Plainwell) sampling locations for comparison.



Plots of the surface water data and regression lines are presented on Figure 5-5. Estimated half-times for surface water data are presented in the following table.

21 Report

Data Locations	**r²** (p<0.01)	**Half-Time (Years)**	**95% Confidence Interval**	
			Lower	**Upper**
Plainwell and all data downstream	0.41	6.1	5.3	7.1
Plainwell	0.43	7.6	6.1	10
Downstream of Allegan City Dam (M-222)	0.60	4.7	4.1	5.7

A substantial body of additional surface water data is being collected by the KRSG. Through July 2000, approximately 22 samples have been collected at each of 13 locations along the Kalamazoo River. These data are compared to historical trends in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

5.2.3 Fish Trend Analysis

> ➢ PCB concentrations in fish between Morrow Lake and Lake Allegan have declined significantly over time, and are predicted to continue to decline.

Trends in fish PCB concentrations were evaluated using several different approaches to control for variables that may affect fish PCB concentrations. Trend analyses seek evidence of changes, if any, in the availability of PCB over time to fish in the Kalamazoo River, including changes produced by natural attenuation processes over time. However, as analyzed in Section 4.6, other factors may affect the concentrations of PCB in fish tissue, most notably the lipid content. The methods used for assessing variations in fish PCB concentration over time differ in approach to account for the effects of these other factors:

1. Linear regression and analyses of wet weight PCB concentrations in size-restricted fish.

2. Linear regression of lipid-adjusted PCB concentrations, which accounts for the variations caused by lipid content, the generally predominant factor contributing variations to fish PCB concentrations at a given location.

3. A multivariate linear regression evaluates simultaneously a number of independent variables potentially affecting PCB concentrations.

~~The most comprehensive fish data sets (both spatially and temporally) for PCB trend analysis are for smallmouth bass and carp fillets. Five [illegible] historical data available as well as data [illegible] 1997~~: near Battle Creek, in Morrow Lake, at Plainwell, in Lake Allegan, and from the lower river near New Richmond. ~~Fish data [illegible] are presented in *Draft Technical Memorandum 14*~~ (BBL, 1994f), data collected in 1997 as part of the fish trend monitoring program are presented in the *Draft Addendum 3 to Draft Technical Memorandum 14* (BBL, 1998), and data collected in 1999 as part of the fish trend monitoring program are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). Results of trend monitoring performed by the MDEQ which analyzed caged catfish samples collected near Saugatuck and whole-body carp samples collected in Lake Allegan were also analyzed.

[redacted]les. These trends were examined for smallmouth bass less than 16 inches and carp less than or equal to 22 inches in length. These size restrictions provide a more consistent historical size class and reduces the potentially confounding effects of the positive correlation between fish size and PCB concentration.

Trend analyses were performed using a first-order decay model. The PCB data were log transformed and a linear regression was performed on the transformed data. The use of the linear regression allows for the generation of statistical parameters (e.g., r^2 and p-value) which can be used to evaluate the statistical confidence and uncertainty of the predicted trend line. The results of the linear regressions yield a line slope (the first-order rate constant) as well as the upper and lower 95% confidence interval around the predicted slope (rate constant). Half-times were calculated from the slope of the regression line. The results of these trend analyses are presented as half-times in Table 5-3.

Predicted trend lines for samples from near Battle Creek, Morrow Lake, former Plainwell Impoundment, and Lake Allegan are presented on Figures 5-6 through 5-9 and summarized in Table 5-4. [redacted] on Figures 5-6 through 5-9 to denote the 95% confidence intervals about the regressed trend curve as well as the predicted populations. As shown on these figures and the summary table, regression analyses of wet-weight PCB in size-restricted fish indicate that carp and smallmouth bass fillet PCB levels have decreased significantly near Battle Creek (6.2- and 12-year half-times for bass and carp, respectively), in Morrow Lake (3.1- and 3.2-year half-times for bass and carp, respectively), in Plainwell (2.7- and 11-year half-times for bass and carp, respectively), and in Lake Allegan (4.6- and 6.3-year half-times for bass and carp, respectively). The regression analysis of PCB concentrations in whole-body carp from Lake Allegan monitored by the MDEQ yielded a half time (5.2 years) which is similar to the Lake Allegan carp fillet data (6.3 years).

Although a clear and consistent picture of declining trends in fish PCB levels is indicated by the data for Lake Allegan and locations upstream through Morrow Lake, [redacted] (upstream). At

Battle Creek, the predicted trend line slopes were not significantly different than zero; however, concentrations at this location have been comparatively low (0.1 mg/kg or less).

[redacted]. As shown on Figure 5-10, data from composite samples of caged channel catfish from the river near Saugatuck demonstrate a significant decline in PCB bioavailability during the period from 1987 to 1996 with a half-time of 4.4 years and an r^2 of 0.84 ($p<0.05$). That half-time is within the relatively narrow range of half times (3.5 to 4.8 years) estimated for PCB in bioavailable sediments estimated from three dated cores from Kalamazoo Lake. Consequently, the calculated half-times for New Richmond carp fillets apparently would underestimate substantially the overall rate of decline of PCB in fish downstream of Lake Allegan.

An additional analysis was performed to examine trends in PCB concentration data corrected for length, weight, lipid, and interspecies variation. The technique used to develop trends in fish tissue PCB concentrations, a modification to the technique used by Stow et al. (1995) to examine 20 years of PCB data from five species of Lake Michigan fish, corrected for the non-temporal independent variables. Fish tissue data for carp and smallmouth bass fillets from Plainwell and Lake Allegan were used in the analysis as well as whole body carp collected by the MDEQ from Lake Allegan. These species and locations were selected for having the best long-term record, from 1983 to 1997. A similar analysis incorporating data collected in 1999 is presented in the *Supplement to the Kalamazoo RI/FS* (BBL, 2000e)

To account for differences between species and locations, data for each variable were standardized to a mean value of 1 by dividing all values by the mean for that variable obtained on a species/location specific basis. For example, all carp length data at Lake Allegan were divided by 16.5, the mean length in inches, to produce a data set with a mean of 1. Smallmouth bass length at Lake Allegan were divided by 14, their mean value. This procedure, while enhancing the ability to aggregate species and locations, does not alter the underlying statistical relationships developed, since the variability in the data sets relative to the mean value remains constant. This procedure is in essence the same as converting data from English to metric units by dividing (or multiplying) by a conversion factor: the fundamental relationship between variables is not altered.

> ➢ Fish PCB concentrations are declining at an average annual rate of 5.9% in Plainwell and 10% in Lake Allegan.

A [redacted]. The regression model included adjusted length, weight, lipid content, time, and a categorized variable related to species. The time variable used was number of years prior to 2000; therefore, data collected in 1993 had a time value of 7. To account for differences in the time periods and intensity of data collection between the two species, a categorized variable was introduced; all carp received a value of 0, while all smallmouth bass received a value of 1. This categorized species variable allowed the regression analysis to offset differences between species caused by unequal temporal coverage over the study period.

Regression models were developed for each location including the year of collection as a variable. The r^2 for the Plainwell and Lake Allegan regression models were 0.76 and 0.77, respectively. The regression models were then run omitting the time variable, but holding the other model parameters constant, and the residuals then exponentiated. Exponentiation returns the residual values to the original metric of PCB concentration. These exponentiated residuals provide an estimate of the PCB concentrations that have been corrected for the independent variables included in the model. Box plots of the adjusted PCB concentrations are shown on Figures 5-11 and 5-12. Note that since the variable has been adjusted, the numerical value of the adjusted concentration is not as important as the temporal rate of change. For Plainwell, the rate of PCB concentration change is -5.9% per year, equivalent to an 11-year half-time. For Lake Allegan, a more rapid change of -10.1% occurred per year, with an associated 6.6-year half-time, was noted.

[redacted] in smallmouth bass and carp samples, the results [redacted]. Based on the observed trends and the results of fish samples collected in conjunction with the RI/FS, [redacted].

5.2.3.1 Indications Regarding Fish Consumption Advisories

> ➢ Comparison of current fish data collected in the 1990s to existing applicable fish consumption advisory criteria indicate that several advisories in the Kalamazoo River could be relaxed or eliminated.

Empirical analyses of the 1993 and 1997 fish data indicate that the current fish consumption advisories can be revised and further indicate a general time frame for eliminating advisories in the future. An updated analysis that uses the most recent fish data available (including a wider array of species from 1997 and 1999) to evaluate the 2000 MDCH fish consumption advisories is presented in the *Supplement to the Kalamazoo River*

RI/FS (BBL, 2000e). That fish consumption advisories can be revised is evident by a comparison of PCB levels in smallmouth bass and carp fillets to fish consumption advisory criteria currently in effect in the State of Michigan. Based on 1993 and 1997 data, only carp from between Morrow Dam and Lake Allegan Dam and downstream of Lake Allegan Dam (e.g., Saugatuck) currently warrant a general population "no consumption advisory." This is quite different from the existing general population advisory, which recommends no consumption of carp, smallmouth bass, and catfish suckers between Morrow Dam and Lake Allegan Dam; no consumption of carp upstream of Morrow Dam; and no consumption of carp, catfish, or northern pike below Lake Allegan Dam (see detailed discussion in Appendix A).

Using the results of fish PCB regression analyses and the Michigan fish consumption advisory criteria, the time at which such criteria would be achieved was estimated for the area covered by the RI. Advisory criteria presented in the following summary table include an average concentration of 1.0 mg/kg, below which children and women of child-bearing age are advised to limit fish consumption to one meal per month, and 0.05 mg/kg, below which there would be no advisory. The estimates of the time until the women and children consumption advisory criteria are achieved were based on the average PCB concentrations in a given size range, consistent with the Great Lakes Sport Fish Advisory Task Force Protocol (Great Lakes Sports Fish Advisory Task Force, 1993).

Also presented in the following table are the predicted times to achieve the unrestricted consumption criteria for the general population, which is based on the distribution of PCB measurements within a sample exceeding 2 mg/kg: if fewer than 11% of samples exceed 2 mg/kg, there is no advisory; if 11 to 49% of the samples exceed 2 mg/kg, the advisory is to eat no more than one meal per week; if half or more of the samples exceed 2 mg/kg, the advisory is to eat no fish. To estimate the time until all advisories could be removed for the general population (i.e., less than 11% of fish with PCB levels greater than 2 mg/kg), the time until average PCB levels in fish reached 1 mg/kg was calculated, consistent with Michigan's 1998 review of their fish advisory program (Michigan Environmental Science Board, 1998): "Based upon experience with this system, MDPH has noted that when 11 percent of the samples exceed a trigger level, the mean concentration is generally about 1/2 of the trigger level. Using PCB with a trigger level of 2.0 ppm, for example, this would occur at a mean concentration of approximately 1.0 ppm."

Estimated Time (Year) to Meet Fish Advisory Criteria

Location	Carp <22 inches			Smallmouth Bass <16 inches		
	General Population	Women & Children		General Population	Women & Children	
		1.0 mg/kg	0.05 mg/kg		1.0 mg/kg	0.05 mg/kg
Battle Creek	CA	CA	2000	CA	CA	CA
Morrow Lake	CA	CA	2008	CA	CA	2001
Plainwell	2008	2008	2056	CA	CA	2008
Lake Allegan	CA	CA	2023	CA	CA	2014

Notes:

1. CA - Criteria achieved.
2. Times estimated by extrapolation of first-order regression curves for wet-weight fillet data.
3. Women and children advisories are based on average PCB concentrations for size ranges of fish, consistent with Great Lakes Sport Fish Advisory Task Force guidance (1993).
4. For general population, time until unlimited fish consumption is when less than 11% of fish exceed 2 mg/kg. This was estimated according to a MDCH convention that, when average PCB levels equal 1.0 mg/kg, fewer than 11% of individual fish exceed 2.0 mg/kg.

To address potential effectiveness/performance of natural attenuation in reducing risk to human health, smallmouth bass data should be given greater weight than carp data. As noted from surveys of Great Lakes anglers and from the Kalamazoo River angler survey recently completed by the ATSDR (2000), there is little catching and eating of carp in comparison to bass species. In developing performance standards for a human health risk-based remedy, therefore, greater weight should be given to current and future levels of PCB in species such as bass.

Finally, the existence of uncontrolled external sources of PCB to the river would result in actual fish PCB trends proceeding towards a non-zero asymptote, rather than a zero asymptote as in the simple extrapolation illustrated here. This is demonstrated by PCB levels in fish upstream of the Site. Given the very low levels of the advisory criteria, upstream loading must be factored into any remedial decision-making. This effect is supported by the apparent shift in the composition of surficial sediment PCB to a higher molecular weight mixture (i.e., ratios of PCB quantitated as Aroclor 1242 to Aroclor 1254 decreasing towards the surface in dated cores) which indicates PCB sources not associated with the paper industry which may have had a different discharge chronology.

5.3 Systems Analysis of the Kalamazoo River

> - The model developed for the Site is applied and reported only in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).
> - Simple calculations used in place of the model are explained and applied in this section.

Development of a quantitative understanding of the transport, bioaccumulation, and fate of PCB in the Kalamazoo River is essential to the development and evaluation of remedial approaches. How much faster will PCB levels in fish decline if external sources of PCB to the Kalamazoo River are controlled? Can infrequent high-flow events scour PCB from Lake Allegan sediments and reverse the downward trend in fish PCB levels there? Answering these and many other important questions regarding PCB in the Kalamazoo River requires some ability to estimate conditions outside of those which have been observed and monitored in the past. This is the role and purpose of systems analysis. For large and complex sites such as the Kalamazoo River, the systems analysis takes the form of linked numerical models of sediment transport, water quality, and bioaccumulation. Examples include those developed for the Hudson River Superfund Site in New York (Connolly et al., 2000) and the New Bedford Harbor Superfund Site in Massachusetts (Battelle, 1990). ~~Such a model has been under development for the Kalamazoo River and is reported on in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).~~ At the direction of the MDEQ, which has not yet reviewed it, this model is not used in this RI/FS. Instead, for the present, the MDEQ has allowed the use of some simple, easily explained calculations to address the need for systems analysis. In the following subsections, such simple calculations are developed and applied to:

- Explain the rates of declining PCB concentrations in Lake Allegan fish;
- Assess the potential importance of PCB loading from the banks of the MDNR-owned former impoundments;
- Assess the potential reversibility of the declining trends in fish PCB levels due to extremely high river flow conditions; and
- Evaluate the need for a better tool to predict the dynamic processes involved in sediment and PCB transport, particularly upstream of Lake Allegan.

What is that?

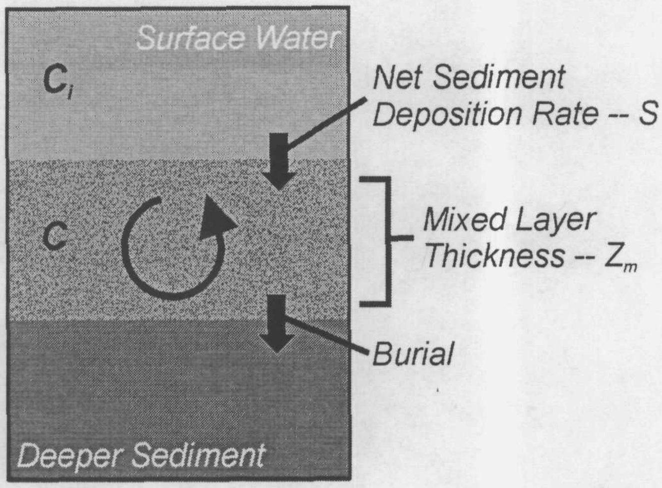
Simple systems analyses indicate that:

- The foremost mechanism responsible for decreasing PCB concentrations in fish is the burial of PCB-containing bed sediment under progressively cleaner sediments;
- High-flow events such as those expected only once every 100 years are unlikely to uncover buried sediments; and

- PCB loading from the banks of the MDNR-owned former impoundments will increase in importance over time and sustain PCB levels in the future; conversely, their control will accelerate the recovery of Lake Allegan.

5.3.1 PCB Burial in Lake Allegan

Lake Allegan plays an important role in the overall fate of PCB in the Kalamazoo River site. The importance of Lake Allegan is evident by its size, comprising roughly two-thirds of the river surface area downstream of Morrow Dam and, as noted by ATSDR (2000), Lake Allegan is an area of significant angling activity.



Sediment deposition, mixing, and burial appear to be the predominant mechanisms responsible for diminishing the bioavailability of PCB in Lake Allegan. A steady supply of sediments from upstream areas and their deposition and mixing in the bioavailable zone (near-surface) sediments predicts mathematically that the bioavailable zone PCB concentration changes exponentially over time toward the concentration of PCB in incoming sediment. Because fish PCB concentrations are determined by bioavailable PCB, trends in fish PCB show a similar exponential decline.

The exponential decline is illustrated in the following simple PCB mass balance for the mixed layer of Lake Allegan. For a constant average thickness of the mixed layer (Z_m), a constant average deposition rate (S), and a PCB concentration on depositing sediment (C_i), the rate of change in PCB concentration in the mixed layer (C) is given by the mass balance equation:

$$\frac{dc}{dt} = \frac{S}{Z_m}(C_i - C) \qquad \text{Equation (1)}$$

The simplest model for initial approximation assumes that the PCB level in incoming sediment (C_i) is zero. Starting with an average sediment PCB concentration of C_o in the mixed layer, a solution to Equation 1 describing how the PCB concentration changes over time is:

$$C = C_o e^{-\frac{S}{Z_m}t} \qquad \text{Equation (2)}$$

Where t is time.

The time to reduce the mixed-layer PCB concentration by 50%, or in other words, the half-time, can be estimated by rearranging Equation 2 for the condition $C/C_o = 0.5$.

$$t_{1/2} = -\frac{-Z_m}{S}(ln\,0.5) \qquad \text{Equation (3)}$$

Site data and other information are available to estimate the net sediment deposition rate, mixing layer thickness, and an initial PCB concentration (C_o) for 1993/1994.

The net deposition rate of sediment can be estimated from measurements of the average thickness of the PCB-containing layer in Lake Allegan, which is approximately 18 inches (45.7 cm), and the estimate, supported from dated RI sediment cores, that very little PCB deposition in the Kalamazoo River occurred prior to the mid-1950s, roughly 45 years prior to the collection of the 1993/1994 cores. This indicates a [redacted]

The thickness of the mixed layer (Z_m) also can be approximated, although with less certainty than the sediment deposition rate. As evident by the results of core samples of fine sediment from Lake Allegan, [redacted] concentrations [redacted] arithmetic averages in these intervals increase for fine sediment from 3.3 mg/kg to 6.6 mg/kg. Inspection of PCB and ^{137}Cs data from finely sectioned cores collected in 1993 and 1995 show generally uniform deposition rates within the top two inches of sediment. (Finely sectioned cores from Lake Allegan were collected in 2000 and analyzed for ^{137}Cs and ^{210}Pb to estimate sediment deposition rates and mixing layer thicknesses. According to MDEQ direction, these data cannot be used in the draft RI/FS, but are presented in the *Supplement to the Kalamazoo River RI/FS* [BBL, 2000e].) Assuming [redacted] reasonable value for the term S/Z_m is 0.2 year^{-1}. As can be seen by Equation 3, the intrinsic half-time given by a mixing layer thickness of 5 cm and a sediment deposition rate of 1 cm/year is 3.5 years. As evident from the inspection of Equations 2 and 3, the slower rates of sediment deposition or greater thicknesses of the mixed layer will produce slower rates of decline in PCB concentration and associated half-times.

While a value of $S/Z_m = 0.2$ year^{-1} seems reasonable, a value of 0.1 year^{-1}, which could correspond to a 100 percent greater mixing layer thickness or 50 percent lower sediment deposition rate, will be used as a more conservative reasonable upper bound on the uncertainty associated with the estimates of S and Z_m. A value of S/Z_m equal to 0.1 year^{-1} is associated with a intrinsic half-time of 6.9 years. As presented previously, estimates of half-times for the decline in Lake Allegan smallmouth bass and carp fillets are 4.6 years and 6.3 years, respectively, and the half-time for PCB in whole-body carp collected over time by the MDEQ is 5.2 years. The analyses of combined standardized fish samples for Lake Allegan indicate an overall average half-time of 6.6 years.

Half-times of PCB levels in fish that are faster than the half-time predicted for sediment (6.9 years) indicates that the intrinsic rate of recovery given by the sediment deposition rates and mixing layer thickness is faster than 0.1 year^{-1}. However, the actual rate of decline in PCB levels in Lake Allegan fish and mixing layer sediment is expected to be less than the theoretical rate of decline (6.9 year half-time) associated with the mixing layer thickness and sediment deposition rate because PCB loading to the lake continues.

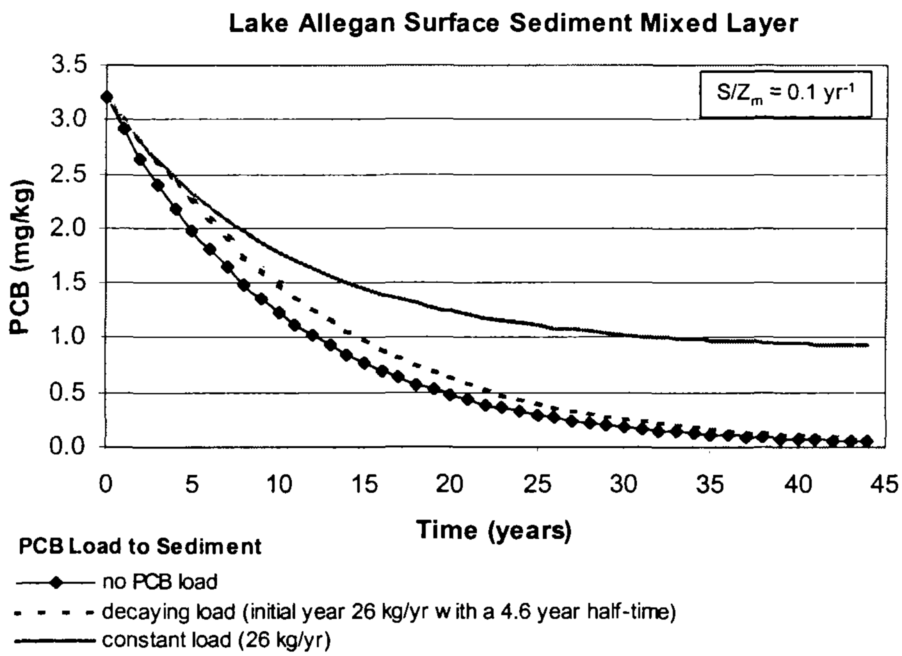
The effects of continued PCB loading on the PCB levels in surface sediments in Lake Allegan can be explicitly analyzed using the simple mass balance model for the mixed layer (see Equation 1). The data from the RI indicate that current PCB levels on suspended solids loaded to Lake Allegan from the Kalamazoo River around 1994 were approximately 1 mg/kg. This is indicated by the average PCB concentrations measured in water samples (0.020 ug/L) and the average level of suspended solids in the same water samples (20 mg/L), assuming all of the PCB in water samples are associated with suspended solids. By comparison, LMMBS data, collected downstream of Lake Allegan, indicate particulate PCB levels ranging from 0.029 to 0.58 mg/kg with an average of 0.29 mg/kg; these values assume only particulate PCB since the dissolved PCB were analyzed separately.

> ➢ If the concentration of transported PCB remains constant over time, PCB levels in the mixed layer will gradually approach the transported concentration of sediment flowing into the system.

Intuitively, if the level of PCB on solids being deposited in Lake Allegan remained constant at 1 mg/kg, the mixed layer average PCB concentration, which was approximately 3.2 mg/kg in 1993/1994 (area-weighted average for fine and coarse sediment), will eventually approach 1 mg/kg. However, as evident from measurements over time, PCB transport in the Kalamazoo River also has been declining with a half-time of approximately 4.6 years or a first-order decay rate of 0.15 year^{-1}.

The simple mass balance representation of the mixed layer illustrates the range in future surface sediment PCB concentration in Lake Allegan based on different assumptions about PCB loading; results are presented in the figure below. The ratio of sedimentation rate to sediment mixed layer thickness S/Z_m in the calculations producing the trend curves below was 0.1 year^{-1}, which, as described earlier, produces an intrinsic half-time of 6.9 years. The curves essentially begin in 1994 and, respectively, show the response to:

- a constant future PCB loading rate of 26 kg/yr;
- an initial PCB loading rate of 26 kg/yr that declines at a rate associated with a 4.6 year half-time (0.15 year^{-1}); and
- the theoretical instant elimination of all of the upstream load of PCB were instantly eliminated in 1994



The curve showing the response to the elimination of external loading in 1994 has the associated half-time of 6.9 years. This appears to be a conservative overestimate considering that the half-times for carp and bass are in the range of 4.5 to 6.3 years. As noted previously, this would indicate that the mixed layer may be assumed to be too thick, that the sedimentation rate is too low, or perhaps both.

~~The fact that all three curves drop relatively sharply in the first several years is attributable to the relatively wide span between the mass of PCB already in the mixed layer and the comparatively small amount of annual PCB load to the sediment.~~ The PCB mass loading to the mixed layer by deposition of sediment in Lake Allegan with a 1 mg/kg concentration is approximately 29 kg/yr. This contrasts to an estimate of 930 kg/yr in the 5 cm mixed layer in Lake Allegan based upon 3.2 mg/kg PCB concentration in the mixed layer. However, as time progresses and the mass of

PCB in the mixed layer becomes smaller due to burial, the PCB load, if it remains constant, exerts increasingly greater and greater control on the PCB levels in surface sediments, eventually approaching the 1 mg/kg PCB concentration on the deposited sediments. In the case of the declining PCB load, it can be seen that if the load continues to decline at that rate of 0.15 year^{-1} (4.6 year half-time) there is little difference between the curve for hypothetical PCB load elimination and that for the declining PCB load.

> ➢ If the contribution of PCB from the banks of the MDNR-owned former impoundments (the most significant identified ongoing source of PCB) decreases over time, contributions of PCB from unidentified and uncontrolled upstream sources will become the controlling factor in determining the PCB concentrations in Lake Allegan surface sediment and fish.

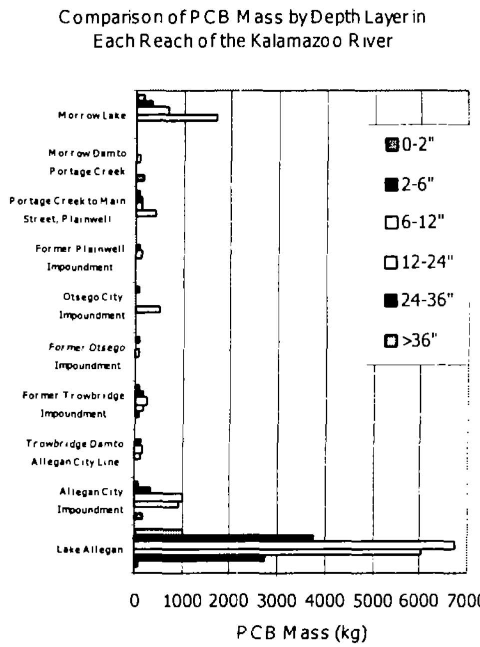
The simple PCB mass balance analysis of the Lake Allegan mixed layer infers several important potential system responses pertinent to the conceptualization of remedial approaches. If PCB loading from the banks of the MDNR-owned former impoundments, which contribute somewhere between 10 and 100 kg of PCB annually to the Kalamazoo River, supplies even the comparatively small amount of 10 to 20 kg PCB, to Lake Allegan sediments on an annual basis over the long term, the effects of underlying physical natural attenuation processes of mixing and burial in the lake would essentially be stalled in the future. Under this conservative scenario, PCB concentrations in the mixed layer would reach a steady-state level in the neighborhood of 0.4 to 0.8 mg/kg. This is evident by proportion to the 29 kg/yr load that results in an approximately 1 mg/kg steady-state mixed layer PCB concentration load. Accordingly, if PCB loading to the lake continued to diminish, or even if all sources of PCB could be instantly eliminated, there would not be much of an incremental benefit to Lake Allegan surface sediment and fish PCB levels.

These results clearly point to the priority for identifying, quantifying, and controlling any upstream sources of PCB that are not diminishing over time. Potential upstream sources include the river bank deposits of the MDNR-owned former impoundments, channel sediments and, most likely, other unquantified external sources (as described previously and in Appendix L).

> ➢ Upstream of Lake Allegan, the vast majority of PCB-containing surface sediment resides in Morrow Lake and the Allegan City Impoundment.

The actual and potential transport of PCB from the various stream channel and river bank components varies considerably. During 1994, PCB transport through the Site was estimated to range from 10 to 26 kg/yr, increasing from roughly 12 kg/yr at Michigan Avenue in Kalamazoo to 28 kg/yr at Farmer Street in Otsego. Estimates of bank loading of PCB to the river from the three MDNR-owned impoundments, which is known by direct observation to occur, are in the range of 10 to 100 kg/yr. Although the magnitude of other external PCB loading is expected to be comparatively small, the proportion of current measured transport attributable to these sources is an open question.

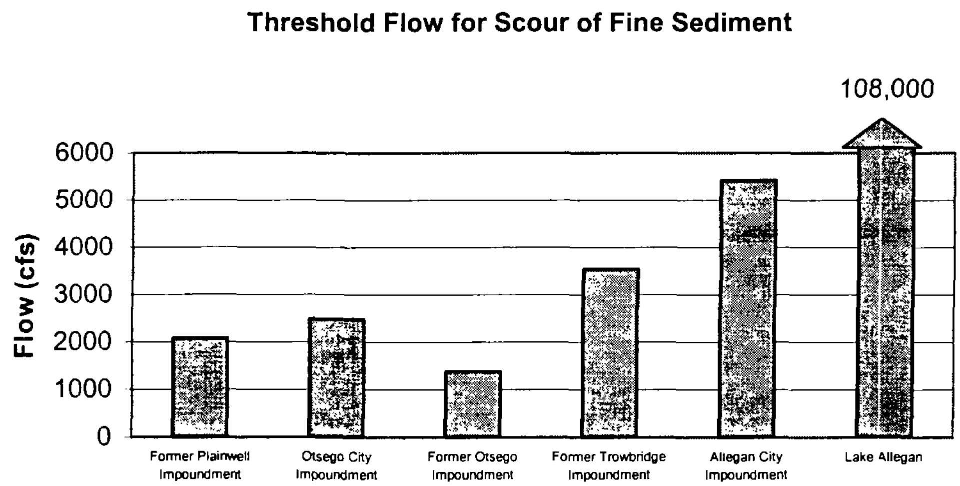
[redacted] directly estimated from the RI [redacted]. It is, however, reasonable to assume that both the deeper sediments found in all segments and the sediments in the impoundments are contributing relatively little PCB to the annual flux. Some indication of the potential for transport is reflected in the mass of PCB found in the surface sediments. Estimation of the PCB mass in the various sections of the river are presented in the figure below by depth. For the sections between Morrow Lake and the Allegan City Impoundment, the amount of PCB in surface sediments (0 to 2 inches) varies from 24 kg to 73 kg, whereas the total mass of PCB in sediments at all depths varies from 240 kg for the former Plainwell Impoundment to 750 kg for the section from Portage Creek to Main Street, Plainwell. The total quantities in Morrow Lake (2,800 kg) and Allegan City Impoundment (2,600 kg) are relatively large by comparison. Surface sediment (0 to 2 inches) of the Allegan City Impoundment have a relatively small mass of PCB (97 kg). It is noteworthy that the mass of PCB in surface sediment in individual sections is of the same magnitude of annual PCB transport in river water flowing through these sections. The implications of this for remedial planning are discussed later.



5.3.2 Potential Effect of High Flow Events

> ➢ Lake Allegan does not appear to be vulnerable to scour, even in the event of a 100-year flood; other impoundments are susceptible to scour by flows expected more frequently than once every three years.

To evaluate the potential for sediment resuspension within the impounded (current and former) sections of the river, the cross sectional areas of the main channel for the three transects immediately upstream of each dam were calculated based upon the probing data collected in 1993. The minimum D_{50} for sediment within those transects based on particle size distribution analysis results was used to estimate the average channel velocity required to produce erosion based on Graf (1971). Multiplying this velocity by the cross-sectional area of the transect at which the minimum D_{50} was observed, the flow at which scour could occur (i.e. threshold flow) was calculated. Based on Graf, flows above these threshold flows would result in incipient motion of the particles on the sediment bed. The results of these calculations for each impoundment are provided in the figure below. It should be noted that the threshold floor is actually calculated for a uniformly distributed sediment, whereas this evaluation used the D_{50} particle size from sediment data. A heterogeneous mixture observed in the Kalamazoo River would actually be more resistant to flow than a uniform sediment bed than indicated by the above calculations.



[redacted] (approximately 13,000 cfs) and more than 14 times the 100-year flow predicted for the Comstock gage station (approximately 7,500 cfs). [redacted] to [redacted]ly. The recurrence for these flows to occur for 15 minutes at Comstock are approximately 1.5 and 3.3 years, respectively. The former Otsego Impoundment had the lowest threshold at 1,380 cfs. These threshold flow estimates are preliminary values generated simply to allow a comparison between locations. [redacted]s. The preliminary results of this modeling effort and a more complete analysis of potential for scour within the specific reaches of the river are presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

The results of a very preliminary assessment of erosion potential indicate that the sediment bed for various sections upstream of Lake Allegan are at, or approaching, a condition of dynamic equilibrium where net sediment deposition may not be occurring, or may be decreasing, with time.

This simplified analysis does not imply a significant potential for erosion deep into the bed of existing or former impoundments where higher PCB concentration may be found. These issues, however, can and will be examined more thoroughly in a sediment transport model under development as described in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

Even without the benefits of a complex model, the overall results of simple systems analysis show that:

1. The decline in fish PCB concentrations in Lake Allegan is proceeding at rates and according to a pattern explained by the natural attenuation process of mixing and burial of sediments in the lake by progressively cleaner sediments.

2. If the diminishing loading of PCB to sediments continues at current rates, there would be no significant benefit to reducing Lake Allegan fish PCB levels by actively remediating upstream sources. However, the effects of these physical processes of natural attenuation can be offset in the future by PCB loading of the magnitude estimated from the banks of the MDNR-owned former impoundments. Such PCB loading eventually would sustain a relatively constant and unacceptable level of PCB in surface sediments if loading from the banks did not diminish over time.

3. The bed of Lake Allegan as a whole appears to be resistant to the potential effects of very high (and rare) river flow given its large cross sectional area. (Other potential mechanisms of erosion, including wind-driven wave action, are analyzed in the *Supplement to the Kalamazoo River RI/FS* [BBL, 2000e]).

4. The preliminary erodibility analysis suggests that, except for Lake Allegan, the other current and former impoundment sections downstream of Morrow Lake are not expected to accumulate substantial amounts of additional fine-grained sediment in the future. This does not mean that continued deposition of coarser sediments will not occur.

5. Considering the magnitude of PCB in Morrow Lake (upstream of the NPL Site and KRSG facilities), there is a need to consider the erodibility of those sediments. Data collected from Morrow Lake sediment and surface water for this purpose are discussed in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

6. The magnitude of annual PCB transport observed in the 1993/1994 period was equal to only a small percentage of the inventory of PCB found in the surface sediments of Lake Allegan (2.6%), but comprised a much larger percentage (27 to 100%) than inventory in surface sediments of individual sections between Lake Allegan and Morrow Lake. In contrast to Lake Allegan, this indicates that the surface sediment PCB

concentrations found in those individual sections of the river are generally more sensitive to transport from upstream reaches.

The use of the simple model for the mixed layer of Lake Allegan is supported by the clear net depositional nature of this large environment. Such simple approximations are not appropriate to represent and predict the surface sediment PCB levels in upstream sections that are not as clearly net depositional. To properly answer the important questions about future PCB levels in surface sediments of those sections of the river, a better representation of sediment transport dynamics is necessary. This has been undertaken in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

5.3.3 Modeling Analysis of PCB and Sediment Transport in the Kalamazoo River

The development, application, and findings of mathematical environmental models of river hydraulics, sediment transport, and PCB fate and transport in the 40 mile stretch of the Kalamazoo River between Morrow Lake and Lake Allegan is described in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e). These modeling tools for the Kalamazoo River have been developed by LTI under the direction of Dr. Joseph DePinto, and applied to support the detailed analysis of remedial alternatives in the Phase I FS for the Kalamazoo River. The principal component of the RI/FS modeling tool is the Kalamazoo River PCB Simulation Model (KALSIM). This model is designed to predict future concentrations of PCB in Kalamazoo River sediment, water, and fish under both a natural attenuation scenario and other sediment management scenarios. The KALSIM model presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e) is similar to mathematical models that have been used at other large-scale sediment sites for the evaluation of remediation strategies. Indeed, although more advanced, this model is similar in many respects to the model of the river developed by the MDNR (NUS, 1986) to evaluate remedial alteration for the Kalamazoo River. The model provides a quantitative framework for the evaluation of the projected relative effectiveness over time of the different remedial alternatives considered in the FS. The full modeling report and detailed supporting information are provided in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

Section 6

6. Risk Assessment

Human health and ecological risks posed by the presence of PCB in the Kalamazoo River have been the subject of a number of completed and ongoing studies, which are summarized in this section. The studies vary in terms of methods, approaches used to characterize exposure and risks posed by chemicals other than PCB, and geographic scope. The pertinent studies of human exposure to PCB and the associated risks include:

- *Preliminary Public Health* (ATSDR, 1991). The MDPH conducted this assessment in 1991 at the outset of RI/FS activities at the Site under an agreement with ATSDR.

- *Kalamazoo River Anglers Survey* (Atkin, 1994). This survey was designed to assess fish consumption patterns in the absence of fish consumption advisories. This survey interviewed 690 anglers in the Kalamazoo River region, and was cited in the Human Health Risk Assessment (HHRA)(CDM, 2000b).

- *Kalamazoo River Angler Survey and Biological Testing Survey* prepared by MDCH and printed by ATSDR (ATSDR, 2000). This study interviewed Kalamazoo River anglers in Kalamazoo and Allegan counties and conducted blood sample analyses for subsets of fish eaters and non-fish eaters.

- *Final Human Health Risk Assessment* (CDM, 2000b). This assessment was performed by CDM on behalf of the MDEQ.

Section Summary

This section presents the evaluations of the possible exposure pathways and risks to humans and biota (e.g., fish, birds) associated with the presence of PCB in the Kalamazoo River that were developed through the RI/FS process. Based on the results of several completed studies and available data from ongoing evaluations, the following conclusions can be drawn:

- Consumption of fish from the Kalamazoo River is the only significant PCB exposure pathway for humans and biota.
- Recreational activities on the river (e.g., boating, swimming) do not pose risks due to PCB.
- Exposed sediment in the three MDNR-owned former impoundments does not present significant risks to people using these areas for recreation.
- Data currently are insufficient to conclude that the transfer of PCB from exposed sediment to the terrestrial community results in significant ecological risk.

Although humans who regularly consume Kalamazoo River fish are potentially subject to increased risk from cancer and non-cancer health effects, a study conducted by the MDCH found that fish eating did not increase PCB levels in blood samples above levels found in the general population.

Observance of fish consumption advisories issued by the MDCH for both the general and sensitive (i.e., children and women of child-bearing age) populations and preparation of fish according to recommended methods are good ways to decrease the potential health risks associated with PCB.

Studies of ecological risk summarized herein include:

- *Baseline Ecological Risk Assessment* (ERA) (CDM, 1999d). This assessment was performed by CDM on behalf of the MDEQ.

- *Addendum to the Baseline Ecological Risk Assessment* (CDM, 2000a).

6.1 Human Health Risk Assessment

> - **Consumption of fish from the river is the only significant pathway that potentially could potentially expose humans to health risks from PCB.**
> - **Recreational activities in the Kalamazoo River (swimming, boating) do not pose PCB-related health risks.**

Collectively, the studies of potential human exposure and risks show that consumption of Kalamazoo River fish is the single pathway of human exposure to PCB at the Site that may lead to some health risk. With one exception that is being studied further as of the preparation of this draft, other potential exposure pathways can be ruled out as not being associated with significant risk. That exception involves the potential for residents living near the three MDNR-owned former impoundments to come in contact with PCB-containing soils near their property. Ongoing studies, discussed in more detail in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e), indicate that this, too, will be eliminated as a pathway of concern.

The 1991 *Preliminary Public Health Assessment* (ATSDR, 1991) provided some early focus on the human exposure pathways identifying potentially significant pathways while eliminating others for consideration. Ingestion of contaminated biota, and incidental ingestion and inhalation of contaminated soils were identified as complete pathways. Drinking surface water and groundwater were eliminated as pathways. The report also concluded that recreational uses of the river, such as swimming, boating, and wading, "would be an insignificant route for exposure due to the low solubility of PCB in water and limited adsorption through the skin."

The 1991 *Preliminary Public Health Assessment* also made note of the PCB levels upstream of the NPL Site in Morrow Lake: "Carp collected from Morrow Lake, upstream of Kalamazoo on the Kalamazoo River, contained up to 12,690 ppb of PCBs in 1986 and up to 5,830 ppb in 1987. Sediment sampled for Morrow Pond in 1988 contained as much as 4,500 ppb PCBs at a depth of 1 to 2 feet with surface concentrations as high as 2,400 ppb," and observed: "The source of the Morrow Pond concentrations have not been more precisely located." At that time, physical and hazards, among others, at the Site included the steep banks and swampy conditions found at certain locations within the fence at the Allied OU, and the potential of the sills of the former Plainwell, Otsego, and Trowbridge dams to cause boats to capsize.

Subsequently, the Kalamazoo River Fishing and Recreation Guide produced by MDCH (1996) emphasized the biota consumption pathway and de-emphasized other potential exposure pathways for those who recreate on the Kalamazoo. The document informed the intended lay public reader that "this site is polluted with PCBs (polychlorinated biphenyls) and other chemicals that may pose a health concern for people who eat certain fish from the Kalamazoo River." The warning also extended to turtles, muskrats, and other animals from the river. The Guide indicated that contact with river muds by recreationists was not a pathway for significant risk. Finally, the Guide provided instruction for preparation and cooking Kalamazoo River fish to reduce PCB levels "by cutting and cooking the fat away."

The HHRA prepared by CDM on behalf of the MDEQ (2000b) focused attention on fish consumption as the high priority pathway, but raised and left unresolved the significance, if any, of the exposure of residents living near the MDNR-owned former impoundments to the exposed former sediments in these areas.

CDM (2000b) quantitatively estimated risks to anglers, individuals hypothetically using the areas of exposed sediment upstream of the former Plainwell, Otsego, and Trowbridge dams for recreation, and residents living near these former impoundments.

The complete summary of the cancer risks and noncancer risks (hazard quotients [HQs] for soils) from the CDM (2000b) HHRA is as follows:

- Cancer risks for residents living near the floodplain soils behind the three MDNR-owned former impoundments are within the USEPA target cancer risk range for the average scenario.

- Cancer risks for residents living near the floodplain soils behind the three MDNR-owned former impoundments are outside the USEPA target cancer risk range, using maximum exposure point concentrations (EPCs).

- Cancer risks for residents living near the floodplain soil behind the three MDNR-owned former impoundments exceed MDEQ thresholds using both average and maximum EPCs.

> ➤ Hazard quotients are used to assess noncancer health risks. A hazard quotient of less than 1.0 indicates no increased risk.

- HQs for residents living near the floodplain soils behind the three MDNR-owned former impoundments exceed the MDEQ and USEPA threshold of 1.0 for the immunological endpoint using both average and maximum EPCs. HQs for the reproductive endpoint do not exceed an HQ of 1.0 using average EPCs. HQs using maximum EPCs exceed the MDEQ and USEPA threshold of 1.0 for the Trowbridge (1.4) and Plainwell (1.5) areas, but not for the Otsego area (0.61).

- Cancer risks for recreationists on the floodplain soil behind the three MDNR-owned former impoundments are within the USEPA target risk range and exceed the MDEQ threshold using maximum EPCs.

- HQs for recreationists on the floodplain soil behind the three MDNR-owned former impoundments are less than the USEPA and MDEQ threshold of 1.0 for both the reproductive and immunological endpoints using average concentrations.

- HQs for recreationists on the floodplain soils behind the three MDNR-owned former impoundments are less than the USEPA and MDEQ threshold of 1.0 for the reproductive endpoint using maximum EPCs. HQs for the immunological endpoint exceeded the threshold of 1.0 for the Trowbridge (2.0) and Plainwell (2.1) areas using maximum EPCs and the HQ for the immunological endpoint for the Otsego area was 0.9.

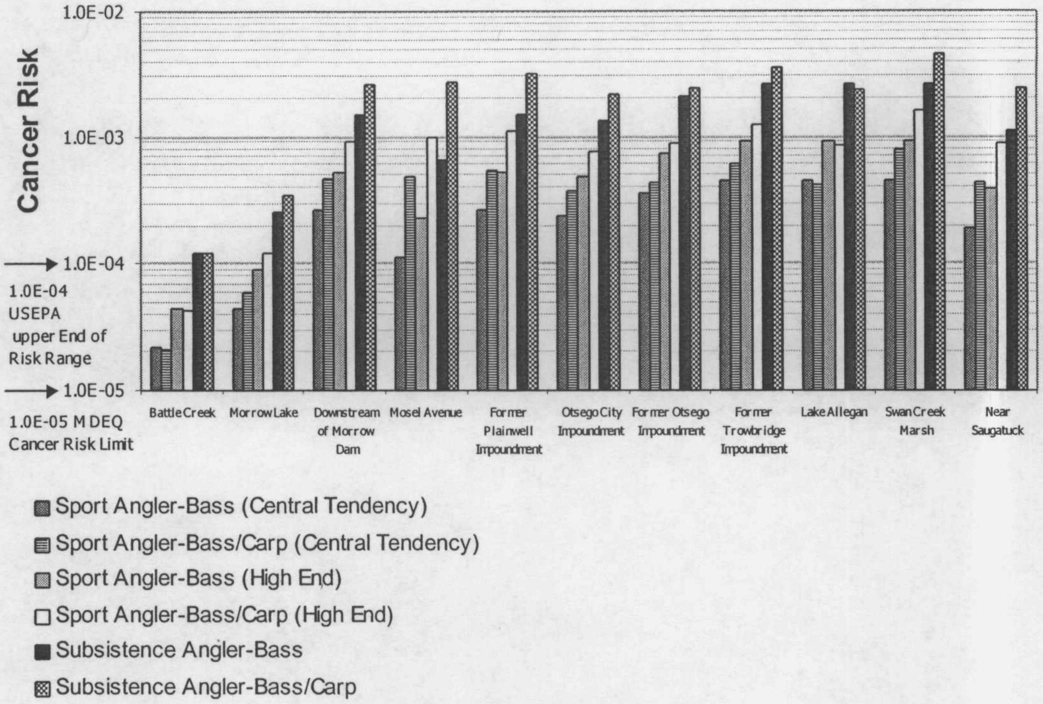
- Cancer risks and HQs for both central tendency and high end sport and subsistence anglers exceed the MDEQ and USEPA risk limits for all scenarios in all ABSAs.

Overall, the results indicate that the exposed sediment in the three MDNR-owned former impoundments does not present unacceptable risks to recreationists. When average PCB levels in the 0- to 6-inch layer of the former impoundments were considered, there were no significant cancer or noncancer risks to recreationists. Even where the maximum sample PCB concentrations were used, noncancer risks were estimated to be below the threshold (i.e., reproductive endpoint) or near the threshold (HQs of 2, 2.1, and 0.9 for the immunological endpoint) for noncancer risks. Estimates of cancer risk using maximum sample PCB concentrations exceeded the MDEQ's 1×10^{-5} threshold (2.1×10^{-5}), but were within USEPA's target risk range of 10^{-6} to 10^{-4}. Considering the conservative nature of the exposure assumptions used to estimate risks to recreationists (e.g., use 128 days/year), existing soil PCB levels in the three MDNR-owned former impoundments do not present a significant risk to recreationists.

As of the drafting of this document, potential exposure of residents to PCB in the exposed sediment has not been conclusively assessed. In the HHRA, CDM observes that "residential property can be found adjacent to the exposed sediments behind Trowbridge and Otsego Dams." Review of aerial photographs, tax maps, and field reconnaissance during July 2000 shows that, while no residential property abuts the Plainwell Impoundment soils, approximately 21 residences are on property adjacent to the Otsego Impoundment soils, and one residential property is adjacent to the Trowbridge Impoundment. The risk assessment notes that "in some areas, the gray paper residual waste can be observed in the back yards of residential homes along the river."

This issue of exposure by residents to PCB in the exposed sediments of the former impoundments is being further assessed by soil sampling directed by the MDEQ based upon the observations of field reconnaissance. The potential area of the impoundments effectively involved in exposure of nearby residents, if any, is relatively small. It is also important to note that the average sample PCB concentration in surface soils within the three MDNR-owned former impoundments [as presented by CDM (2000b)] are only a factor of two or three of the generic residential soil cleanup level for PCB (4.0 mg/kg) under Part 201.

The CDM HHRA emphasized the importance of fish consumption: "Fish ingestion is the primary exposure pathway for the Site. Using maximum and average exposure point concentrations for six different patterns of potential fish consumption (ranging from average sport angler consumption of the smallmouth bass to subsistent angler consumption of a mixture of smallmouth bass and carp), the assessment of all exposures exceeded MDEQ and USEPA thresholds for cancer and noncancer risks." The figure below presents cancer and noncancer risk estimates made by CDM using average fish PCB data. In this figure, the results for Battle Creek/Ceresco Impoundment and Morrow Lake have been added. Morrow Lake and the Battle Creek areas were not addressed in the HHRA, even though fish were collected from these locations as part of the same collections used by CDM for risk assessment.



Risks associated with PCB levels in Morrow Lake and Battle Creek fish were estimated according to CDM's methods by simply scaling fish exposure point PCB concentrations for Morrow Lake and Battle Creek to those used by CDM to represent downstream areas. As illustrated in the figure above and Figures 6-1 and 6-2, risks associated with consumption of fish from Morrow Lake exceed the MDEQ's thresholds for cancer risk and immunologic noncancer risks for all fish consumption patterns by sport and subsistence anglers. Average PCB levels in Battle Creek fish also exceed MDEQ's cancer risk threshold when using CDM's (2000b) methods.

> ➤ In an ATSDR study, Kalamazoo River fish consumers had PCB levels consistent with those found in the general population. The study of Kalamazoo River anglers found no difference between PCB levels in the blood of fisheaters and those in the non-fisheating group when adjusted for the significant effects of age

ATSDR (2000) investigated the patterns of fishing and fish consumption by Kalamazoo River anglers and the nature of their resulting exposure to PCB. ATSDR interviewed 938 Kalamazoo River anglers. Lake Allegan, Verberg Park, and Merrill Park in Comstock were identified as the major fishing spots along the river. Anglers were fishing primarily for recreation, although 2.9 percent reported fishing as a source of food, and an additional 10.6 percent for recreation and as a source of food. A total of 44 percent of anglers reported eating some fish. Bass, catfish, panfish, walleye, and pike were the major species targeted by recreational anglers as well as those using the fish as a food source. The 1994 Atkin survey generally supports this pattern of preference.

Levels of PCB in blood samples taken from people who eat fish from the Kalamazoo River were not significantly elevated. In the ~~ATSDR (2000) study~~, subsets of the anglers, fisheaters, and non-fisheaters had their blood serum analyzed for PCB. Only age differences between the fish eating and non-fish eating groups, rather than fish consumption, accounted for differences in PCB levels between the two groups. Both fisheaters and non-fisheater groups had PCB levels in blood serum that are consistent with those found in the general population. Lower PCB levels were found in Kalamazoo River anglers than in previously studied Lake Michigan anglers, a fact attributed to lower consumption rates of fish and the lower and decreasing PCB levels in those fish: "… species collected from the river no longer have the excessive PCB levels recorded in collection a decade or more ago" (ATSDR, 2000).

> ➢ **Fish consumption advisories issued by the MDCH for both the general and sensitive populations are one way to mitigate human health risks.**

PCB levels in fish in the Kalamazoo River are of concern to the MDCH, which has issued recreational fish consumption advisories related to PCB and mercury in Kalamazoo River fish. Fish consumption advisories also are in effect for mercury in the lakes formed by dams along the Kalamazoo River (MDCH, 1996). However, based upon currently available information, the accumulation of PCB in fish and the transfer to humans is the sole pathway of concern with respect to human exposure to PCB at the Site.

Various levels of PCB in fish can be considered safe for various degrees of human consumption or exposure. The following summarizes a number of such threshold PCB concentrations, including those estimated in the HHRA for protection of human health, and those used by the MDCH to set fish consumption advisories, and that associated with Michigan's statewide water quality standard.

2 mg/kg	The USFDA's tolerance level, which is used by the MDCH to set fish consumption advisories for the general population. When 11 to 49% of fish from a given area exceed 2 mg/kg in their fillets, a "no more than a meal a week advisory" is issued. If 50% or more of the fish exceed 2 mg/kg then "no consumption" is advised.
1.1 - 1.9 mg/kg	Used by the MDCH to advise women and children to limit consumption to 6 meals per year when the average PCB concentration falls in this range.
0.21 - 1.0 mg/kg	Used by the MDCH to advise women and children to eat no more than 1 meal per month when average PCB concentrations fall in this range.

0.06 - 0.2 mg/kg	Used by the MDCH to advise women and children to eat no more than 1 meal per week when average PCB concentrations fall in this range.
0.042 mg/kg	Estimated by CDM (2000b) to be protective of a sport angler consuming 24 meals per year at the 10^{-5} cancer risk level.
0.023 mg/kg	Fish PCB concentration implicit to the 10^{-5} cancer-risk-based Michigan water quality standard of 0.000026 µg/L.
0.021 mg/kg	Estimated by CDM (2000b) to be protective of a "high end" sport angler consuming 125 meals per year at the 10^{-5} cancer risk level.
0.008 mg/kg	Estimated by CDM (2000b) to be protective of a subsistence angler consuming 179 meals (90 lbs) per year at a 10^{-5} cancer risk level.

The HHRA also presents noncancer risk-based fish PCB levels which range from 0.016 to 0.26 mg/kg, depending upon endpoint and fish consumption rates.

Reduction of human exposure to PCB through fish consumption is the exclusive pathway for human exposure to be addressed by remedial alternatives based upon currently available information. This is subject to change based upon the result of recent soil sampling and assessment in, on, or near residential properties adjacent to the MDNR-owned impoundments.

6.2 Ecological Risk Assessment

Screening-level calculations of ecological exposure and potential risk conducted at the time of preparing this RI report indicate that, as with human health, the primary exposure pathway that needs to be addressed further is the transfer of PCB through aquatic organisms to higher-trophic levels. Additional information is also needed to conclusively evaluate the exposed sediments of the former impoundments as a source of ecological risk through terrestrial food web pathways. A portion of this additional data is provided and discussed in the *Supplement of the Kalamazoo River RI/FS* (BBL, 2000e).

6.2.1 Screening Level Risk Assessment

Site ecological risks were assessed using screening-level methods by CDM (CDM, 1999d; 2000a) and are being assessed using a more detailed assessment of actual ecological exposure and toxicity of PCB mixtures present at the Site (Giesy, 2000). Screening-level risk assessments are designed to be highly conservative so that ecological receptors with any potential for risk are carried through for a more detailed site-specific evaluation of risk. The ERA concluded that certain groups of ecological receptors were not at risk. These included: ?

What does "not at risk" mean?

- Fish such as salmonids, smallmouth bass, suckers, and carp; ?
- Aquatic invertebrates; and
- Aquatic plants.

Certain other ecological receptors were considered to potentially be at risk:

- Omnivorous birds (e.g., robins) and small mammals would be at significant risk only if PCB uptake in plants was as high as the levels predicted by the plant bioaccumulation model;
- Bald eagles "may be at risk" if subject to long-term exposure to PCBs in fish; and
- Impaired reproduction of mink and associated decreases in mink populations are the most likely effects of PCB contamination in aquatic prey.

A review of CDM's exposure estimates reveals that consumption of fish predominates the estimates of PCB exposure for mink and bald eagles. The further evaluation of potential risks to mink and bald eagles associated with the consumption of fish is being addressed by ongoing studies that will be included in the final Baseline Ecological Risk Assessment (BERA) produced. CDM's calculations indicate that PCB accumulation in plants growing in PCB-containing soil predominates the exposure of omnivorous birds. CDM relied on exposure assumptions to draw these conclusions, rather than actual field measurements or observations. As presented in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e), actual measurements of PCB levels in plants growing in the PCB-containing soils of the former impoundments lead to substantially different conclusions.

While the screening-level methods used by CDM (1999d) did permit the confident conclusion that certain ecological receptors including aquatic plants, aquatic invertebrates, and carnivorous terrestrial receptors are not at risk, these methods resulted in a series of biases that significantly overestimate risk to other ecological receptors, particularly those ingesting terrestrial plants. As a result of those biases, the methods employed by CDM (1999d) do not provide not agree a sound scientific basis to appropriately conclude that there is significant risk to ecological receptors at the levels of PCB exposure that were represented by CDM (1999d). These biases have been documented by other scientists, and are discussed and addressed in the *Supplement to the Kalamazoo River RI/FS* (BBL, 2000e).

we agree Report is being revised

Section 7

Site Conceptual Model

Section 7

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

References

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

References

Tables

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

Tables

TABLE 4-1

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF KALAMAZOO RIVER SEDIMENT PCB CONCENTRATIONS (mg/kg) BY DEPTH, RIVER REACH, AND SEDIMENT TEXTURE

0- to 2-Inch Depth Interval

Reach	Morrow Dam to Portage Creek		Portage Creek to Main Street, Plainwell		Former Plainwell Impoundment		Otsego City Impoundment		Former Otsego Impoundment
Sediment Texture	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**
Number of Samples	111	23	143	37	17	20	14	22	26
Number of Non-detects	75	8	36	6	2	7	1	6	6
Arithmetic Average	0.14	4.5	0.73	2.2	0.45	11	0.17	8.0	0.20
Arithmetic Upper 95% Confidence Limit	0.22	12	1.7	4.6	0.83	22	0.30	18	0.42
Arithmetic Lower 95% Confidence Limit	0.061	0.001	0.001	0.001	0.080	0.001	0.045	0.001	0.001
Geometric Mean	0.049	0.19	0.092	0.44	0.16	0.67	0.11	0.58	0.077
Geometric Upper 95% Confidence Limit	0.060	0.51	0.12	0.77	0.34	2.3	0.19	1.6	0.12
Geometric Lower 95% Confidence Limit	0.040	0.073	0.073	0.26	0.077	0.19	0.062	0.21	0.050
Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	3.7	86	69	44	2.5	100	0.86	94	2.8

Reach	Former Otsego Impoundment	Former Trowbridge Impoundment		Trowbridge Dam to Allegan City Line		Allegan City Impoundment		Lake Allegan	
Sediment Texture	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**
Number of Samples	11	17	31	27	21	20	31	4	69
Number of Non-detects	3	6	9	11	2	4	1	0	4
Arithmetic Average	15	0.096	4.8	0.12	1.6	0.19	4.4	1.4	3.3
Arithmetic Upper 95% Confidence Limit	47	0.15	11	0.18	2.1	0.34	8.2	4.0	5.5
Arithmetic Lower 95% Confidence Limit	0.001	0.041	0.001	0.059	1.0	0.040	0.53	0.001	1.2
Geometric Mean	0.62	0.067	0.53	0.066	0.79	0.096	1.1	0.61	1.2
Geometric Upper 95% Confidence Limit	3.5	0.10	1.1	0.10	1.7	0.16	2.0	12	1.7
Geometric Lower 95% Confidence Limit	0.11	0.044	0.25	0.044	0.37	0.057	0.62	0.031	0.78
Minimum	ND	ND	ND	ND	ND	ND	ND	0.048	ND
Maximum	160	0.46	91	0.62	3.2	1.5	49	3.7	73

See Notes on Page 5

TABLE 4-1

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF KALAMAZOO RIVER SEDIMENT PCB CONCENTRATIONS (mg/kg) BY DEPTH, RIVER REACH, AND SEDIMENT TEXTURE

2- to 6-Inch Depth Interval

Reach	Morrow Dam to Portage Creek		Portage Creek to Main Street, Plainwell		Former Plainwell Impoundment		Otsego City Impoundment		Former Otsego Impoundment
Sediment Texture	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**
Number of Samples	111	23	143	37	17	20	14	22	26
Number of Non-detects	56	7	51	8	2	10	4	10	5
Arithmetic Average	0.14	4.9	0.48	1.6	0.92	11	0.11	2.4	0.31
Arithmetic Upper 95% Confidence Limit	0.20	12	1.1	3.1	2.0	25	0.15	4.9	0.74
Arithmetic Lower 95% Confidence Limit	0.078	0.001	0.001	0.065	0.001	0.001	0.063	0.001	0.001
Geometric Mean	0.053	0.25	0.071	0.20	0.23	0.33	0.083	0.28	0.090
Geometric Upper 95% Confidence Limit	0.066	0.70	0.088	0.37	0.50	1.2	0.13	0.68	0.14
Geometric Lower 95% Confidence Limit	0.043	0.087	0.057	0.11	0.10	0.094	0.052	0.12	0.057
Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	2.5	74	42	20	7.6	130	0.29	22	5.5

Reach	Former Otsego Impoundment	Former Trowbridge Impoundment		Trowbridge Dam to Allegan City Line		Allegan City Impoundment		Lake Allegan	
Sediment Texture	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**
Number of Samples	11	17	31	27	21	20	31	4	69
Number of Non-detects	3	13	14	15	3	9	5	0	5
Arithmetic Average	6.1	0.16	5.9	1.0	2.8	0.086	8.0	1.4	6.6
Arithmetic Upper 95% Confidence Limit	18	0.36	11	2.5	4.7	0.12	13	5.5	9.4
Arithmetic Lower 95% Confidence Limit	0.001	0.001	1.0	0.001	0.85	0.050	2.8	0.001	3.7
Geometric Mean	0.36	0.047	0.33	0.070	0.72	0.062	1.1	0.22	1.4
Geometric Upper 95% Confidence Limit	1.9	0.085	0.82	0.13	1.8	0.091	2.7	10	2.3
Geometric Lower 95% Confidence Limit	0.069	0.026	0.13	0.036	0.29	0.042	0.45	0.0048	0.87
Minimum	ND	ND	ND	ND	ND	ND	ND	0.027	ND
Maximum	59	1.7	51	18	17	0.33	57	5.3	59

See Notes on Page 5

TABLE 4-1

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF KALAMAZOO RIVER SEDIMENT PCB CONCENTRATIONS (mg/kg) BY DEPTH, RIVER REACH, AND SEDIMENT TEXTURE

6- to 12-Inch Depth Interval

Reach	Morrow Dam to Portage Creek		Portage Creek to Main Street, Plainwell		Former Plainwell Impoundment		Otsego City Impoundment		Former Otsego Impoundment
Sediment Texture	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**
Number of Samples	106	23	125	37	11	19	13	21	23
Number of Non-detects	43	4	47	10	2	10	4	9	5
Arithmetic Average	0.10	3.6	0.20	1.6	1.3	11	0.10	1.9	0.33
Arithmetic Upper 95% Confidence Limit	0.15	10	0.30	3.1	2.9	26	0.15	4.1	0.82
Arithmetic Lower 95% Confidence Limit	0.059	0.001	0.10	0.011	0.001	0.001	0.054	0.001	0.001
Geometric Mean	0.049	0.20	0.058	0.14	0.27	0.31	0.076	0.28	0.086
Geometric Upper 95% Confidence Limit	0.059	0.46	0.072	0.27	0.87	1.2	0.13	0.67	0.14
Geometric Lower 95% Confidence Limit	0.041	0.090	0.047	0.076	0.083	0.081	0.045	0.12	0.052
Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	1.9	74	3.7	20	7.6	130	0.29	22	5.5

Reach	Former Otsego Impoundment	Former Trowbridge Impoundment		Trowbridge Dam to Allegan City Line		Allegan City Impoundment		Lake Allegan	
Sediment Texture	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**
Number of Samples	11	15	31	25	21	17	31	4	69
Number of Non-detects	3	11	14	16	3	8	6	0	10
Arithmetic Average	6.1	0.078	5.7	1.1	2.6	0.089	16	1.4	7.8
Arithmetic Upper 95% Confidence Limit	18	0.15	10	2.7	4.5	0.13	25	5.5	11
Arithmetic Lower 95% Confidence Limit	0.001	0.0060	0.94	0.001	0.80	0.045	6.7	0.001	4.8
Geometric Mean	0.36	0.043	0.32	0.063	0.70	0.062	1.7	0.22	1.5
Geometric Upper 95% Confidence Limit	1.9	0.070	0.80	0.13	1.7	0.096	4.6	11	2.6
Geometric Lower 95% Confidence Limit	0.069	0.026	0.13	0.031	0.29	0.040	0.60	0.0045	0.85
Minimum	ND	ND	ND	ND	ND	ND	ND	0.027	ND
Maximum	59	0.48	51	18	17	0.33	86	5.3	67

See Notes on Page 5

TABLE 4-1

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF KALAMAZOO RIVER SEDIMENT PCB CONCENTRATIONS (mg/kg) BY DEPTH, RIVER REACH, AND SEDIMENT TEXTURE

12- to 24-Inch Depth Interval

Reach	Morrow Dam to Portage Creek		Portage Creek to Main Street, Plainwell		Former Plainwell Impoundment		Otsego City Impoundment		Former Otsego Impoundment
Sediment Texture	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**
Number of Samples	66	21	65	28	6	15	5	20	14
Number of Non-detects	22	4	13	3	4	8	0	9	4
Arithmetic Average	0.085	0.45	1.1	0.34	0.049	1.5	5.3	0.84	0.12
Arithmetic Upper 95% Confidence Limit	0.14	1.1	3.2	0.92	0.062	3.4	19	2.1	0.18
Arithmetic Lower 95% Confidence Limit	0.034	0.001	0.001	0.001	0.036	0.001	0.001	0.001	0.063
Geometric Mean	0.042	0.10	0.055	0.056	0.048	0.15	0.49	0.094	0.083
Geometric Upper 95% Confidence Limit	0.052	0.20	0.076	0.088	0.065	0.46	12	0.20	0.14
Geometric Lower 95% Confidence Limit	0.034	0.053	0.040	0.036	0.035	0.048	0.020	0.044	0.049
Minimum	ND	ND	ND	ND	ND	ND	0.037	ND	ND
Maximum	1.5	6.3	67	7.9	0.060	13	25	11	0.32

Reach	Former Otsego Impoundment	Former Trowbridge Impoundment		Trowbridge Dam to Allegan City Line		Allegan City Impoundment		Lake Allegan	
Sediment Texture	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**	**COARSE**	**FINE**
Number of Samples	9	5	30	11	19	8	31	3	68
Number of Non-detects	5	1	14	7	9	2	5	1	22
Arithmetic Average	0.55	0.17	1.9	0.36	1.2	2.0	6.2	3.7	3.2
Arithmetic Upper 95% Confidence Limit	1.1	0.53	3.3	0.98	2.2	6.7	11	17	4.9
Arithmetic Lower 95% Confidence Limit	0.040	0.001	0.57	0.001	0.14	0.001	1.9	0.001	1.5
Geometric Mean	0.17	0.069	0.18	0.064	0.21	0.098	0.67	0.71	0.40
Geometric Upper 95% Confidence Limit	0.69	0.35	0.42	0.18	0.57	0.57	1.7	1200	0.69
Geometric Lower 95% Confidence Limit	0.043	0.014	0.081	0.022	0.079	0.017	0.27	0.00041	0.23
Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	1.6	0.69	12	3.1	7.1	16	47	9.7	44

See Notes on Page 5

TABLE 4-1

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF KALAMAZOO RIVER SEDIMENT PCB CONCENTRATIONS (mg/kg) BY DEPTH, RIVER REACH, AND SEDIMENT TEXTURE

Samples Deeper Than 24 Inches

Reach	Morrow Dam to Portage Creek		Portage Creek to Main Street, Plainwell		Former Plainwell Impoundment		Otsego City Impoundment		Former Otsego Impoundment
Sediment Texture	COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE
Number of Samples	7	3	1	4	4	8	3	14	11
Number of Non-detects	0	0	1	0	3	6	0	9	3
Arithmetic Average	5.4	0.40	ND	0.042	0.051	0.060	0.44	0.080	0.46
Arithmetic Upper 95% Confidence Limit	18	1.6		0.081	0.061	0.074	2.2	0.15	0.84
Arithmetic Lower 95% Confidence Limit	0.001	0.001		0.0032	0.041	0.045	0.001	0.011	0.079
Geometric Mean	0.084	0.18	ND	0.038	0.051	0.058	0.13	0.051	0.21
Geometric Upper 95% Confidence Limit	1.0	14		0.083	0.061	0.072	18	0.081	0.53
Geometric Lower 95% Confidence Limit	0.0070	0.0023		0.018	0.042	0.046	0.00088	0.033	0.082
Minimum	0.029	0.029	ND	0.028	ND	ND	0.032	ND	ND
Maximum	38	0.97	ND	0.079	0.060	0.099	1.2	0.47	1.6

Reach	Former Otsego Impoundment	Former Trowbridge Impoundment		Trowbridge Dam to Allegan City Line		Allegan City Impoundment		Lake Allegan	
Sediment Texture	FINE	COARSE	FINE	COARSE	FINE	COARSE	FINE	COARSE	FINE
Number of Samples	7	4	24	2	4	6	27	2	53
Number of Non-detects	5	2	13	2	2	4	15	1	35
Arithmetic Average	0.28	0.19	0.91	0.030	0.31	0.38	0.24	0.045	1.7
Arithmetic Upper 95% Confidence Limit	0.82	0.67	1.7	0.033	1.1	0.98	0.57	0.20	3.7
Arithmetic Lower 95% Confidence Limit	0.001	0.001	0.16	0.027	0.001	0.001	0.001	0.001	0.001
Geometric Mean	0.089	0.070	0.12	0.030	0.10	0.097	0.062	0.043	0.078
Geometric Upper 95% Confidence Limit	0.30	0.77	0.27	0.033	1.6	0.67	0.096	1.4	0.12
Geometric Lower 95% Confidence Limit	0.026	0.0064	0.054	0.027	0.0067	0.014	0.039	0.0013	0.050
Minimum	ND	ND	ND	ND	ND	ND	ND	ND	ND
Maximum	1.6	0.64	6.2	0.030	1.1	1.4	4.4	0.057	45

Notes:
Samples from some cores were depth-weighted to provide the uniform depth intervals presented (e.g., a 2 to 12" sample was used to represent both the 2 to 6" and 6 to12" intervals).
Duplicate values were averaged.
Values reported as not detected were counted as 1/2 the detection limit.

TABLE 4-2

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
RESULTS OF KALAMAZOO RIVER SEDIMENT DATA REGRESSION ANALYSES

	log(PCB) Versus															Multivariate Model [log(PCB) predicted by]						
	Velocity			Sediment Depth			Distance			TOC			Percent Silt & Clay			Whole Model			TOC	Distance	Percent Silt & Clay	Sediment Depth
	n	p	r^2	n	p	r^2	n	p	r^2	n	p	r^2	n	p	r^2	n	p	r^2	r^2	r^2	r^2	r^2
Samples From the Surficial Depth Interval																						
Morrow Lake	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Morrow Dam to Portage Creek	43	< 0.001	0.282	133	0.001	0.077	133	< 0.001	0.143	132	< 0.001	0.242	89	< 0.001	0.222	89	< 0.001	0.427	0.051	0.048	0.031	0.090
Portage Creek to Main St., Plainwell	48	< 0.001	0.349	180	0.030	0.026	180	0.091	0.016	179	< 0.001	0.025	74	0.077	0.043	74	< 0.001	0.303	0.228	NS	NS	NS
Former Plainwell Impoundment	10	0.476	0.065	37	0.961	0.000	37	0.423	0.018	36	0.003	0.229	--	--	--	36	0.012	0.286	0.259	NS	--	NS
Otsego City Impoundment	12	0.198	0.160	36	0.017	0.157	36	0.121	0.069	36	< 0.001	0.342	--	--	--	36	0.001	0.400	0.201	NS	--	NS
Former Otsego Impoundment	9	0.458	0.081	37	0.660	0.006	37	0.553	0.010	36	< 0.001	0.382	--	--	--	36	0.001	0.403	0.332	NS	--	NS
Former Trowbridge Impoundment	11	0.002	0.666	48	< 0.001	0.312	48	0.003	0.177	46	< 0.001	0.244	6	0.002	0.928	46	< 0.001	0.444	0.146	NS	--	0.136
Trowbridge Dam to Allegan City Line	12	0.061	0.308	48	0.010	0.137	48	0.826	0.001	47	< 0.001	0.604	3	0.118	0.966	47	< 0.001	0.605	0.451	NS	--	NS
Allegan City Impoundment	10	0.067	0.360	51	< 0.001	0.344	51	< 0.001	0.278	50	< 0.001	0.412	13	< 0.001	0.771	13	0.001	0.867	NS	NS	0.497	NS
Lake Allegan	--	--	--	73	0.005	0.106	73	0.011	0.088	72	< 0.001	0.229	32	< 0.001	0.390	32	0.004	0.419	NS	NS	0.116	NS
All Reaches	157	< 0.001	0.271	643	< 0.001	0.187	643	< 0.001	0.171	634	< 0.001	0.364	218	< 0.001	0.453	218	< 0.001	0.548	0.030	0.013	0.036	0.022
Samples From All Depth Intervals																						
Morrow Lake	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Morrow Dam to Portage Creek	165	< 0.001	0.334	465	< 0.001	0.109	465	< 0.001	0.170	426	< 0.001	0.223	249	< 0.001	0.117	233	< 0.001	0.382	0.060	0.112	0.011	0.063
Portage Creek to Main St., Plainwell	143	< 0.001	0.219	560	0.168	0.003	560	0.001	0.019	527	< 0.001	0.168	151	0.120	0.016	130	< 0.001	0.164	0.136	NS	NS	NS
Former Plainwell Impoundment	24	0.386	0.034	108	0.031	0.043	108	0.010	0.061	79	0.417	0.009	35	0.408	0.021	19	0.464	0.214	NS	NS	NS	NS
Otsego City Impoundment	33	0.711	0.004	115	0.537	0.003	115	0.957	0.000	78	0.002	0.121	33	0.049	0.119	19	0.077	0.432	0.328	NS	NS	NS
Former Otsego Impoundment	33	0.754	0.003	129	0.036	0.034	129	0.905	0.000	83	0.034	0.054	36	0.002	0.252	18	0.237	0.328	NS	NS	NS	NS
Former Trowbridge Impoundment	37	0.036	0.120	169	< 0.001	0.181	169	< 0.001	0.134	123	< 0.001	0.345	57	< 0.001	0.188	41	< 0.001	0.636	0.145	NS	NS	0.114
Trowbridge Dam to Allegan City Line	27	0.003	0.304	128	< 0.001	0.158	128	0.910	0.000	78	< 0.001	0.424	46	< 0.001	0.415	18	0.100	0.428	NS	NS	NS	NS
Allegan City Impoundment	41	0.002	0.214	198	< 0.001	0.143	198	< 0.001	0.086	168	< 0.001	0.187	67	< 0.001	0.543	54	< 0.001	0.457	NS	NS	0.232	NS
Lake Allegan	--	--	--	312	< 0.001	0.031	312	0.047	0.013	247	< 0.001	0.083	111	< 0.001	0.407	93	< 0.001	0.376	NS	NS	0.277	NS
All Reaches	513	< 0.001	0.211	2184	< 0.001	0.139	2184	< 0.001	0.125	1809	< 0.001	0.213	785	< 0.001	0.288	625	< 0.001	0.358	0.043	0.009	0.039	0.016

Notes:
Shading indicates a statistically significant relationship at a level of $p<0.05$.
NS indicates that no statistical relationship exists at a level of $p<0.05$.
n indicates the sample size used in the regression analysis.
p indicates the significance level of the regression.
r^2 value describes the amount of variation explained by a given parameter.
-- indicates that parameter was not included in the regression analysis due to small sample size.
TBD - to be determined upon receipt of 2000 data.
Surficial depth interval was typically 0- to 2-inches in depth but did include some samples from 0- to 6-inches as well.

TABLE 4-3

ALLIED PAPER INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
ESTIMATED PCB MASS AND SEDIMENT VOLUME IN KALAMAZOO RIVER REACHES

Reach	Area (acres)	Total Sediment (1) (cy)	PCB-Containing Sediment (2) (cy)	Estimated PCB Mass (kg)
Morrow Lake	1,000	TBD	2,541,000	2,831
Morrow Dam to Portage Creek	112	350,000	58,000	345
Portage Creek to Main Street, Plainwell	331	950,000	341,000	754
Main Street, Plainwell to Plainwell Dam	44	99,000	53,000	241
Plainwell Dam to Otsego City Dam	96	415,000	224,000	695
Otsego City Dam to Otsego Dam	83	290,000	191,000	306
Otsego Dam to Trowbridge Dam	131	542,000	263,000	719
Trowbridge Dam to Allegan City Line	190	450,000	258,000	476
Allegan City Line to Allegan City Dam	127	748,000	417,000	2,562
Allegan City Dam to Lake Allegan Dam	1,649	10,163,100	5,143,000	20,363
Kalamazoo River Total	3,763	14,007,100	9,489,000	29,292
Portage Creek	7	33,600	23,050	162

Notes:
Estimates for Morrow Lake are subject to change based on receipt of 2000 data.
TBD - to be determined following receipt of 2000 data.
Calculations and methods for final values are presented in Appendix B.
(1) Based on total depth of sediment determined during sediment probing/core collection.
(2) Based on depth of sediment in which PCB were detected in analyzed cores, and weighted by sediment texture (fine or coarse) and frequency of PCB detection.

TABLE 4-4

ALLIED PAPER INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF PHYSICAL AND ANALYTICAL RESULTS OF FOCUSED SAMPLING

			Physical Data									
			Solids (%)					Silt and Clay (%)				
Focused Core Location Category/Depth	Number of Cores	Number of Samples	Minimum	Maximum	Arithmetic Mean[1]	Geometric Mean[1]	Median	Minimum	Maximum	Arithmetic Mean[1]	Geometric Mean[1]	Median
Former Impoundment Exposed Sediment[2]												
Surface (0- to 6-inch)	14	14	23	64	48	46	51	41	95	72	69	72
All Depths (0- to 24-inch)		52	22	85	55	52	56	6.4	98	66	57	71
Floodplain[2]												
Surface (0- to 6-inch)	34	34	15	90	56	58	56	0.90	93	56	40	60
All Depths (0- to 24-inch)		114	15	94	63	65	64	0.30	94	43	28	43
Kalamazoo River Sediment												
Surface (0- to 2-inch)	39	39	18	88	50	44	41	1.9	99	54	34	70
All Depths (0- to 24-inch)		164	12	93	54	50	45	1.3	100	52	32	57
Kalamazoo River Islands												
Surface (0- to 6-inch)	10	10	49	85	63	62	60	7.9	79	47	38	50
All Depths (0- to 24-inch)		30	47	88	67	66	66	4.3	79	36	27	32
Point Source and Waste Disposal[2]												
Surface (0- to 6-inch)	8	8	28	78	63	59	73	5.9	94	40	23	15
All Depths (0- to 24-inch)		29	20	94	69	66	73	3.2	94	32	18	13
Otsego City Impoundment												
Surface (0- to 6-inch)	10	10	15	95	43	37	36	8.4	98	67	54	76
All Depths (0- to 24-inch)		34	13	92	48	40	45	2.0	99	51	35	57

(See notes on page 2)

TABLE 4-4

ALLIED PAPER INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF PHYSICAL AND ANALYTICAL RESULTS OF FOCUSED SAMPLING

Focused Core Location Category/Depth	Number of Cores	Number of Samples	Analytical Data: Total Organic Carbon (%) Minimum	Maximum	Arithmetic Mean[1]	Geometric Mean[1]	Median	PCB Concentration (mg/kg) Minimum	Maximum	Arithmetic Mean[1]	Geometric Mean[1]	Median
Former Impoundment Exposed Sediment[2]												
Surface (0- to 6-inch)	14	14	4.2	15	9.0	8.4	10	ND	68	17	3.8	4.2
All Depths (0- to 24-inch)		52	0.14	15	6.9	5.1	7.9	ND	130	13	1.6	2.8
Floodplain[2]												
Surface (0- to 6-inch)	34	34	0.23	24	6.7	4.3	6.2	ND	15	1.3	0.32	0.34
All Depths (0- to 24-inch)		114	0.072	28	4.6	2.2	2.6	ND	20	1.1	0.15	0.055
Kalamazoo River Sediment												
Surface (0- to 2-inch)	39	39	0.097	36	7.4	3.9	8.2	ND	27	2.2	0.77	1.5
All Depths (0- to 24-inch)		164	0.056	42	6.1	3.1	6.7	ND	120	6.9	0.96	1.5
Kalamazoo River Islands												
Surface (0- to 6-inch)	10	10	1.8	14	6.4	5.5	6.5	ND	9.2	3.4	1.3	2.7
All Depths (0- to 24-inch)		30	ND	14	4.2	2.4	3.6	ND	15	2.2	0.40	0.34
Point Source and Waste Disposal[2]												
Surface (0- to 6-inch)	8	8	0.26	14	5.2	3.1	4.5	0.10	3.6	0.73	0.34	0.26
All Depths (0- to 24-inch)		29	0.14	25	4.9	2.2	2.1	ND	220	9.3	0.33	0.23
Otsego City Impoundment												
Surface (0- to 6-inch)	10	10	1.4	37	15	9.0	14	ND	9.1	3.0	0.49	0.18
All Depths (0- to 24-inch)		34	0.16	45	14	5.6	10	ND	33	2.0	0.19	0.11

NOTES:

1 Mean of all samples within indicated depth interval. One-half the detection limit was used as a proxy concentration for non-detects.

2 Sediment cores analyzed as 0- to 2-inch and 2- to 6-inch depth intervals were weighted to represent the 0- to 6-inch depth interval prior to surficial averaging.

ND - Not detected

TABLE 4-5

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
RESULTS OF KALAMAZOO RIVER SURFACE WATER REGRESSION ANALYSES

Location	Year (s)	PCB Versus									Multivariate Model [PCB predicted by]								
		TSS			Temp			Flow			Whole Model			TSS		Temp		Flow	
		n	p	r^2	n	p	r^2	n	p	r^2	n	p	r^2	p	r^2	p	r^2	p	r^2
LMMBS Total	1994-1995	38	0.153	0.056	38	<0.001	0.298	38	0.0072	0.184	38	<0.001	0.410	0.189	<0.001	0.004	0.166	0.032	0.087
LMMBS Particulate	1994-1995	38	0.118	0.067	38	0.002	0.231	38	0.0119	0.163	38	0.002	0.351	0.142	0.043	0.018	0.117	0.044	0.084
LMMBS Dissolved	1994-1995	38	0.730	0.003	38	<0.001	0.454	38	0.0113	0.165	38	<0.001	0.504	0.826	<0.001	<0.001	0.334	0.078	0.048
Farmer St (SWK4)	1994	32	0.310	0.034	32	<0.001	0.315	31	0.486	0.017	31	0.009	0.342	0.974	<0.001	0.003	0.267	0.384	0.019
M-222 (SWK5)	1994	31	0.304	0.036	30	0.024	0.170	25	0.901	0.001	24	0.080	0.281	0.343	0.034	0.018	0.239	0.303	0.040
M-89 (SWK6)	1994	17	0.232	0.094	16	0.347	0.063	12	0.474	0.052	12	0.612	0.193	0.359	0.096	0.826	0.005	0.603	0.030
Portage Creek (SWP3a)	1994	31	0.033	0.147	31	0.016	0.184	31	0.998	<0.001	31	0.022	0.295	0.056	0.104	0.232	0.039	0.102	0.075

Notes:
Shading indicates a statistically significant relationship at a level of $p<0.05$.
n indicates the sample size used in the regression analysis.
p indicates the significance level of the regression.
r^2 value describes the amount of variation explained by a given parameter.

TABLE 4-6

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF 1993 FISH DATA

ABSA	n	Length (cm)			Weight (g)			Wet-weight PCB (mg/kg)			Lipid (%)			Lipid-adjusted PCB (mg/kg-lipid)		
		Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation
Carp - (Skin-off Fillets)																
ABSA 1	11	57	4.1	7.2	440	81	18	0.083	0.034	41	1.2	0.76	63	8.6	6.1	71
ABSA 2	11	62	8.4	14	650	330	51	0.61	0.53	87	1.1	1.1	100	64	27	42
ABSA 3	11	56	5.3	9.5	690	220	32	4.4	3.5	80	3.6	2.1	58	150	76	51
ABSA 4	11	59	4.6	7.8	760	170	22	6.6	3.5	53	6.1	3.9	64	120	41	34
ABSA 5	11	57	4.5	7.9	610	130	21	5.8	4.4	76	5.3	3.6	68	120	45	38
ABSA6	11	56	5.3	9.5	660	170	26	3.5	2.5	71	2.9	2.7	93	180	120	67
ABSA 7	11	55	6.7	12	570	150	26	2.7	1.9	70	2.3	1.8	78	130	74	57
ABSA 8	11	53	7.4	13	480	230	48	4.6	2.8	61	1.6	1.5	94	360	200	56
ABSA 9	11	46	1.5	3.3	300	71	24	1.8	1.7	94	1.4	0.84	60	130	77	59
ABSA 10	11	62	12	19	1300	1100	85	7.6	5.2	68	10	11	110	190	180	95
ABSA 11	11	59	9.3	16	950	730	77	5.0	3.1	62	8.1	6.4	79	100	93	93
ABSA 12	11	51	4.1	8.0	NA	NA	NA	3.4	2.1	62	1.5	0.46	31	230	140	61
Smallmouth Bass - Adults (Skin-on Fillets)																
ABSA 1	11	3[illegible]	3.1	8.4	300	70	23	0.14	0.081	58	1.4	0.55	39	9.1	2.8	31
ABSA 2	11	35	5.1	15	220	110	50	0.28	0.18	64	0.86	0.51	59	35	15	43
ABSA 3	11	33	3.4	10	190	60	32	1.1	0.81	74	1.3	0.75	58	85	29	34
ABSA 4	11	33	3.7	11	170	49	29	0.48	0.17	35	0.79	0.38	48	67	28	42
ABSA 5	11	35	3.8	11	200	58	29	1.8	0.82	46	1.2	0.49	41	160	56	35
ABSA6	11	35	3.9	11	230	67	29	0.99	0.95	96	1.6	1.0	63	84	73	87
ABSA 7	11	36	4.2	12	240	84	35	1.5	0.92	61	0.86	0.51	59	180	69	38
ABSA 8	11	34	2.8	8.2	170	34	20	2.0	0.94	47	0.88	0.45	51	240	84	35
ABSA 9	11	36	4.4	12	320	150	47	3.3	1.4	42	2.9	1.2	41	120	39	33
ABSA 10	11	36	4.2	12	290	110	38	1.9	0.43	23	1.8	0.61	34	120	30	25
ABSA 11	11	29	5.2	18	150	100	67	0.54	0.22	41	0.87	0.24	28	64	26	41

(See notes on page 2)

TABLE 4-6

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF 1993 FISH DATA

ABSA	n	Length (cm)			Weight (g)			Wet-weight PCB (mg/kg)			Lipid (%)			Lipid-adjusted PCB (mg/kg-lipid)		
		Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation
Suckers - (Whole-body)																
ABSA 1	11	23	5.3	23	140	100	71	0.076	0.034	45	0.85	0.20	24	8.9	3.3	37
ABSA 2	11	14	1.2	8.6	33	8.9	27	0.54	0.16	30	2.6	0.76	29	22	8.6	39
ABSA 3	11	19	1.9	10	74	23	31	0.81	0.16	20	5.6	0.89	16	14	1.7	12
ABSA 4	11	19	3.8	20	87	69	79	2.3	0.46	20	3.9	1.2	31	62	15	24
ABSA 5	11	17	1.6	9.4	54	16	30	2.2	0.54	25	2.7	0.80	30	87	26	30
ABSA6	11	22	4.1	19	130	60	46	2.2	1.0	45	3.2	1.4	44	72	23	32
ABSA 7	11	24	6.4	27	170	110	65	2.1	0.44	21	3.1	0.58	19	71	14	20
ABSA 8	11	22	3.3	15	120	61	51	0.81	0.30	37	0.81	0.21	26	100	41	41
ABSA 9	11	19	1.2	6.3	73	11	15	0.82	0.40	49	0.75	0.17	23	110	44	40
ABSA 10	11	27	3.4	13	230	91	40	0.35	0.25	71	1.0	0.28	28	38	30	79
ABSA 11	11	24	2.0	8.3	130	41	32	1.1	0.22	20	2.2	1.0	45	57	26	46
ABSA 12	11	20	4.2	21	99	65	66	1.4	0.76	54	1.3	0.52	40	110	57	52

Notes
ABSA - Aquatic biota sampling area
ABSA 1 - Near Battle Creek
ABSA 2 - Morrow Lake
ABSA 3 - Upstream of Portage Creek
ABSA 4 - Near Mosel Avenue in Kalamazoo
ABSA 5 - Upstream of Plainwell Dam
ABSA 6 - Plainwell Dam to Otsego City Dam
ABSA 7 - Upstream of Otsego Dam
ABSA 8 - Upstream of Trowbridge Dam
ABSA 9 - Lake Allegan
ABSA 10 - Swan Creek Marsh
ABSA 11 - Near New Richmond
ABSA 12 - Portage Creek (Bryant Mill Pond)
n - Sample size

TABLE 4-7

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF 1997 FISH DATA

ABSA	n	Length (cm)			Weight (g)			Wet-weight PCB (mg/kg)			Lipid (%)			Lipid-adjusted PCB (mg/kg-lipid)		
		Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation
Carp - (Skin-off Fillets)																
ABSA 1	11	56	3.7	6.6	2500	460	18	0.088	0.067	76	0.75	0.36	48	11	4.1	37
ABSA 2	11	60	9.3	16	3000	1400	47	0.26	0.21	81	0.44	0.26	59	54	18	33
ABSA 5	11	61	9.1	15	3700	1900	51	5.9	5.7	97	5.7	5.3	93	120	49	41
ABSA 9	11	48	1.9	4.0	1400	260	19	0.72	0.48	67	0.55	0.44	80	150	68	45
ABSA 11	11	58	6.8	12	3200	1500	47	4.7	5.0	110	6.5	6.2	95	87	65	75
Smallmouth Bass - Adults (Skin-on Fillets)																
ABSA 1	11	38	2.6	6.8	890	200	22	0.047	0.018	38	0.50	0.22	44	11	6.6	60
ABSA 2	11	36	4.2	12	680	290	43	0.11	0.092	84	0.40	0.17	43	26	17	65
ABSA 5	11	37	1.3	3.5	650	99	15	0.46	0.37	80	0.26	0.14	54	170	84	49
ABSA 9	11	37	2.6	7.0	660	170	26	0.49	0.40	82	0.49	0.31	63	120	100	83
ABSA 11	12	38	3.1	8.2	860	220	26	1.1	1.3	120	0.52	0.21	40	230	280	120
Smallmouth Bass - Yearling (Whole-body Composites)																
ABSA 1	5	15	0.26	1.7	48	1.6	3.3	0.24	0.070	29	1.5	0.28	19	16	5.2	33
ABSA 2	5	16	1.7	11	54	15	28	0.27	0.058	21	0.74	0.49	66	47	22	47
ABSA 5	5	16	0.53	3.3	53	4.0	7.5	2.5	0.86	34	1.8	0.16	8.9	140	50	36
ABSA 9	6	17	2.9	17	60	25	42	1.6	0.72	45	2.5	0.56	22	69	37	54
ABSA 11	5	18	0.55	3.1	69	7.3	11	1.2	0.12	10	1.7	0.50	29	75	23	31

Notes
ABSA - Aquatic biota sampling area
ABSA 1 - Near Battle Creek
ABSA 2 - Morrow Lake
ABSA 5 - Upstream of Plainwell Dam
ABSA 9 - Lake Allegan
ABSA 11 - Near New Richmond
n - Sample size

TABLE 4-7

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
SUMMARY OF 1997 FISH DATA

ABSA	n	Length (cm)			Weight (g)			Wet-weight PCB (mg/kg)			Lipid (%)			Lipid-adjusted PCB (mg/kg-lipid)		
		Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation	Arithmetic Mean	Standard Deviation	Coefficient of Variation
Carp - (Skin-off Fillets)																
ABSA 1	11	56	3.7	6.6	2500	460	18	0.088	0.067	76	0.75	0.36	48	11	4.1	37
ABSA 2	11	60	9.3	16	3000	1400	47	0.26	0.21	81	0.44	0.26	59	54	18	33
ABSA 5	11	61	9.1	15	3700	1900	51	5.9	5.7	97	5.7	5.3	93	120	49	41
ABSA 9	11	48	1.9	4.0	1400	260	19	0.72	0.48	67	0.55	0.44	80	150	68	45
ABSA 11	11	58	6.8	12	3200	1500	47	4.7	5.0	110	6.5	6.2	95	87	65	75
Smallmouth Bass - Adults (Skin-on Fillets)																
ABSA 1	11	38	2.6	6.8	890	200	22	0.047	0.018	38	0.50	0.22	44	11	6.6	60
ABSA 2	11	36	4.2	12	680	290	43	0.11	0.092	84	0.40	0.17	43	26	17	65
ABSA 5	11	37	1.3	3.5	650	99	15	0.46	0.37	80	0.26	0.14	54	170	84	49
ABSA 9	11	37	2.6	7.0	660	170	26	0.49	0.40	82	0.49	0.31	63	120	100	83
ABSA 11	12	38	3.1	8.2	860	220	26	1.1	1.3	120	0.52	0.21	40	230	280	120
Smallmouth Bass - Yearling (Whole-body Composites)																
ABSA 1	5	15	0.26	1.7	48	1.6	3.3	0.24	0.070	29	1.5	0.28	19	16	5.2	33
ABSA 2	5	16	1.7	11	54	15	28	0.27	0.058	21	0.74	0.49	66	47	22	47
ABSA 5	5	16	0.53	3.3	53	4.0	7.5	2.5	0.86	34	1.8	0.16	8.9	140	50	36
ABSA 9	6	17	2.9	17	60	25	42	1.6	0.72	45	2.5	0.56	22	69	37	54
ABSA 11	5	18	0.55	3.1	69	7.3	11	1.2	0.12	10	1.7	0.50	29	75	23	31

Notes
ABSA - Aquatic biota sampling area
ABSA 1 - Near Battle Creek
ABSA 2 - Morrow Lake
ABSA 5 - Upstream of Plainwell Dam
ABSA 9 - Lake Allegan
ABSA 11 - Near New Richmond
n - Sample size

TABLE 4-8

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

COEFFICIENTS OF DETERMINATION (r^2) FOR PCB VS. OTHER PARAMETERS - 1993 DATA

Location	Coefficients of Determination (r^2)										
	Near Battle Creek	Morrow Lake	Upstream of Portage Creek	Near Mosel Avenue in Kalamazoo	Upstream of Plainwell Dam	Plainwell Dam to Otsego City Dam	Upstream of Otsego Dam	Upstream of Trowbridge Dam	Lake Allegan	Swan Creek Marsh	Near New Richmond
Smallmouth Bass - Adults (Skin-on Fillets)											
Length	0.066	0.014	0.68[1]	0.27	0.063	0.0088	0.30	0.0047	0.010	0.013	0.018
Weight	0.047	0.037	0.64[1]	0.23	0.031	0.0039	0.36	0.025	0.0030	0.076	0.014
K	0.12	0.14	0.039	0.33	0.015	0.033	0.13	0.037	0.048	0.30	0.11
Lipid	0.74[1]	0.50[1]	0.73[1]	0.48[1]	0.18	0.012	0.71[1]	0.73[1]	0.55[1]	0.25	0.096
Carp - (Skin-off Fillets)											
Length	0.11	0.31	0.19	0.091	0.36	0.044	0.017	0.0025	0.32	0.0086	0.22
Weight	0.13	0.27	0.35	0.077	0.32	0.0050	0.034	0.032	0.041	< 0.0010	0.21
K	0.0024	0.23	0.30	0.066	0.045	0.12	0.067	0.44[1]	0.043	0.094	0.16
Lipid	0.66[1]	0.82[1]	0.016	0.85[1]	0.62[1]	0.049	0.41[1]	0.55[1]	0.36	< 0.0010	0.16
Suckers - (Whole-body)											
Length	0.042	0.25	0.38[1]	0.39[1]	0.0066	0.46[1]	0.095	0.12	0.071	< 0.0010	0.12
Weight	0.032	0.14	0.37[1]	0.39[1]	< 0.0010	0.48[1]	0.17	0.070	0.022	< 0.0010	0.15
K	0.049	0.085	0.088	0.11	0.011	0.23	0.41[1]	0.0031	0.12	0.019	0.052
Lipid	0.27	0.019	0.67[1]	0.56[1]	0.27	0.47[1]	0.25	0.15	0.36[1]	0.065	0.096

Note:
1. Significant value ($p<0.05$)

TABLE 4-9

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

COEFFICIENTS OF DETERMINATION (r^2) FOR PCB VS. OTHER PARAMETERS - 1997 DATA

Location	Coefficients of Determination (r^2)				
	Near Battle Creek	**Morrow Lake**	**Upstream of Plainwell Dam**	**Lake Allegan**	**Near New Richmond**
Carp - (Skin-off Fillets)					
Length	0.017	0.0011	0.84[1]	0.0062	0.21
Weight	0.096	0.012	0.95[1]	0.22	0.19
K	0.24	0.0057	0.50[1]	0.54[1]	0.095
Lipid	0.70[1]	0.93[1]	0.93[1]	0.22	0.31
Smallmouth Bass - Adults (Skin-on Fillets)					
Length	0.063	< 0.0010	0.35	0.013	0.091
Weight	0.14	0.011	0.69[1]	< 0.0010	0.10
K	0.11	0.34	0.34	0.036	0.018
Lipid	0.26	0.032	0.80[1]	0.51[1]	0.0023
Smallmouth Bass - Yearling (Whole-body Composites)					
Lipid	NA	0.59	0.050	0.30	0.63

Notes:

1. Significant value ($p<0.05$)

NA - Data not available.

TABLE 5-1

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
ESTIMATED ANNUAL PCB LOAD IN THE KALAMAZOO RIVER AND PORTAGE CREEK (KG/YEAR)

Method		River St.[1]	Michigan Ave.[1]	Farmer St.[2]	M-222[2]	M-89[2]	LMMBS[3]	Portage Creek
	Q_{USGS}(cfs)	890	960	1232	1409	1480	1830	50
	$\overline{Q}$ (cfs)	1608	2100	2237	2142	2312	2295	76
1	Load = Q_{USGS} x C_{DL} x 0.002445 x 365	20	21	28	31	33	41	--
2	Load = Q_{USGS} x $\overline{C_i}$ x 0.002445 x 365	11	12	29	33	32	38	4.7
3	Load = ($\overline{Q_i}$ x $\overline{C_i}$) x 0.002445 x 365	20	25	52	50	50	47	7.0
4	Load = $\overline{L_i}$ x 365	20	25	50	50	49	44	7.0
5	Stratified by flow increment	10	12	28	26	25	39	4.2
	Range	10-20	12-25	28-52	26-50	25-50	38-47	4.2-7.0
	Midpoint	15	18.5	40	38	37.5	42.5	5.6

Notes:

[1] Assumes arithmetic mean where non-detections were counted as one-half the method detection limit. Due to the large number of non-detects, descriptive statistics could not be estimated.

[2] Applies estimated PCB distribution statistics developed using the robust methods described in Helsel (1990) to obtain sample means.

[3] LMMBS data were collected by USEPA as part of the Lake Michigan Mass Balance Study from April 1994 to October 1995. PCB load calculations were based on the sum of particulate and dissolved PCB congener concentrations. All other locations were sampled by BBL in 1994.

Q_{USGS} = Mean flow determined from USGS gaging station record or from basin-area adjustment of gaging station records

Q_i = Instantaneous discharge during sample collection from measurement of flow or stage

$\overline{Q_i}$ = Mean of instantaneous discharges (Σ Q_i)/N

C_i = Total PCB concentration for sample i

$\overline{C_i}$ = Mean concentration (Σ C_i)/N

C_{DL} = Method Detection limit = 0.025 ug/l

N = Number of samples (or flow measurements)

L_i = instantaneous load = C_i x Q_i * .002445

$\overline{L_i}$ = Mean instantaneous load (Σ L_i/N)

0.002445 is a unit conversion constant

TABLE 5-2

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER AND PORTAGE CREEK
1994 SURFACE WATER INVESTIGATION

River Street							Michigan Avenue						
A	B	C	D	E	F	G	A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)	Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 341	0.05	0.05	0.0125	0.0104	3.80	0.190	<= 382	0.05	0.05	0.0125	0.0117	4.26	0.213
342 - 402	0.05	0.1	0.0125	0.0114	4.14	0.207	383 - 450	0.05	0.1	0.0125	0.0127	4.64	0.232
403 - 494	0.1	0.2	0.0125	0.0137	5.00	0.500	451 - 549	0.1	0.2	0.0125	0.0153	5.57	0.557
495 - 572	0.1	0.3	0.0125	0.0163	5.95	0.595	550 - 635	0.1	0.3	0.0260	0.0376	13.74	1.374
573 - 650	0.1	0.4	0.0125	0.0187	6.82	0.682	636 - 721	0.1	0.4	0.0193	0.0320	11.68	1.168
651 - 742	0.1	0.5	0.0125	0.0213	7.76	0.776	722 - 822	0.1	0.5	0.0125	0.0236	8.61	0.861
743 - 855	0.1	0.6	0.0125	0.0244	8.91	0.891	823 - 944	0.1	0.6	0.0125	0.0270	9.85	0.985
856 - 1000	0.1	0.7	0.0125	0.0283	10.35	1.035	945 - 1100	0.1	0.7	0.0125	0.0312	11.40	1.140
1001 - 1200	0.1	0.8	0.0125	0.0336	12.27	1.227	1101 - 1311	0.1	0.8	0.0125	0.0368	13.45	1.345
1201 - 1540	0.1	0.9	0.0184	0.0616	22.50	2.250	1312 - 1670	0.1	0.9	0.0125	0.0456	16.63	1.663
1541 - 1870	0.05	0.95	0.0125	0.0521	19.02	0.951	1671 - 2027	0.05	0.95	0.0154	0.0696	25.40	1.270
> 1870	0.05	1	0.0125	0.0622	22.70	1.135	> 2027	0.05	1	0.0125	0.0674	24.60	1.230
			Total Flow-Stratified PCB Load Estimate (kg) =			10				Total Flow-Stratified PCB Load Estimate (kg) =			12

(See notes on page 4)

TABLE 5-2

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER AND PORTAGE CREEK
1994 SURFACE WATER INVESTIGATION

Farmer Street						
A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 491	0.05	0.05	0.0710	0.0852	31.11	1.556
492 - 575	0.05	0.1	0.0710	0.0925	33.77	1.689
576 - 694	0.1	0.2	0.0710	0.1101	40.20	4.020
695 - 802	0.1	0.3	0.0710	0.1298	47.39	4.739
803 - 906	0.1	0.4	0.0125	0.0261	9.53	0.953
907 - 1031	0.1	0.5	0.0125	0.0296	10.80	1.080
1032 - 1177	0.1	0.6	0.0125	0.0337	12.32	1.232
1178 - 1364	0.1	0.7	0.0450	0.1398	51.02	5.102
1365 - 1603	0.1	0.8	0.0125	0.0453	16.55	1.655
1604 - 2012	0.1	0.9	0.0140	0.0619	22.58	2.258
2013 - 2440	0.05	0.95	0.0153	0.0833	30.39	1.520
> 2440	0.05	1	0.0206	0.1337	48.79	2.440
			Total Flow-Stratified PCB Load Estimate (kg) =			28

M-222						
A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 606	0.05	0.05	0.0275	0.0407	14.87	0.744
607 - 707	0.05	0.1	0.0275	0.0441	16.11	0.806
708 - 847	0.1	0.2	0.0340	0.0646	23.58	2.358
848 - 979	0.1	0.3	0.0268	0.0598	21.84	2.184
980 - 1102	0.1	0.4	0.0197	0.0501	18.29	1.829
1103 - 1253	0.1	0.5	0.0125	0.0360	13.14	1.314
1254 - 1425	0.1	0.6	0.0125	0.0409	14.94	1.494
1426 - 1643	0.1	0.7	0.0209	0.0784	28.61	2.861
1644 - 1913	0.1	0.8	0.0195	0.0848	30.94	3.094
1914 - 2375	0.1	0.9	0.0224	0.1174	42.86	4.286
2376 - 2879	0.05	0.95	0.0125	0.0803	29.31	1.465
> 2879	0.05	1	0.0239	0.1830	66.78	3.339
			Total Flow-Stratified PCB Load Estimate (kg) =			26

(See notes on page 4)

TABLE 5-2

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER AND PORTAGE CREEK
1994 SURFACE WATER INVESTIGATION

M-89

A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 646	0.05	0.05	0.0280	0.0442	16.14	0.807
647 - 753	0.05	0.1	0.0280	0.0479	17.48	0.874
754 - 900	0.1	0.2	0.0280	0.0566	20.65	2.065
901 - 1040	0.1	0.3	0.0280	0.0664	24.24	2.424
1041 - 1170	0.1	0.4	0.0280	0.0756	27.61	2.761
1171 - 1330	0.1	0.5	0.0260	0.0795	29.00	2.900
1331 - 1510	0.1	0.6	0.0193	0.0670	24.46	2.446
1511 - 1740	0.1	0.7	0.0125	0.0497	18.13	1.813
1741 - 2020	0.1	0.8	0.0125	0.0575	20.97	2.097
2021 - 2500	0.1	0.9	0.0125	0.0691	25.21	2.521
2501 - 3030	0.05	0.95	0.0229	0.1548	56.51	2.825
> 3030	0.05	1	0.0125	0.1007	36.76	1.838
				Total Flow-Stratified PCB Load Estimate (kg) =		25

Portage Creek

A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 30	0.028	0.028	0.1120	0.0082	3.00	0.084
31 - 35	0.033	0.061	0.1120	0.0089	3.25	0.107
36 - 40	0.11	0.171	0.1120	0.0103	3.75	0.412
41 - 45	0.168	0.339	0.1120	0.0116	4.25	0.714
46 - 50	0.172	0.511	0.0850	0.0099	3.60	0.620
51 - 55	0.12	0.631	0.0125	0.0016	0.59	0.070
56 - 60	0.112	0.743	0.1500	0.0211	7.70	0.862
61 - 65	0.084	0.827	0.0810	0.0124	4.52	0.380
66 - 70	0.057	0.884	0.0970	0.0160	5.84	0.333
71 - 75	0.034	0.918	0.0870	0.0154	5.63	0.191
76 - 80	0.027	0.945	0.0830	0.0157	5.74	0.155
81 - 85	0.013	0.958	0.0790	0.0159	5.82	0.076
86 - 90	0.011	0.969	0.0945	0.0202	7.38	0.081
91 - 95	0.005	0.974	0.1100	0.0249	9.08	0.045
96 - 100	0.005	0.979	0.0613	0.0146	5.33	0.027
101 - 110	0.006	0.985	0.0125	0.0032	1.17	0.007
111 - 120	0.005	0.990	0.0150	0.0042	1.54	0.008
121 - 130	0.001	0.999	0.0650	0.0199	7.25	0.007
131 - 240	0.001	0.9995	0.1150	0.0520	18.99	0.019
				Total Flow-Stratified PCB Load Estimate (kg) =		4.2

(See notes on page 4)

TABLE 5-2

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER AND PORTAGE CREEK
1994 SURFACE WATER INVESTIGATION

Notes:

A Flow increment for individual PCB load estimate, which was weighted by frequency of occurrence to derive an estimate of annual PCB load.

B Approximate fraction of time, on an annual basis, that flow at the sampling location is within the flow range in Column A. Flow frequencies were based on USGS records: SWK-1 directly from the USGS gage at Comstock (USGS 0410600; 1932-1979, 1984-1993), SWK-6 directly from the USGS gage at Fennville (USGS 04108500; 1937-1993), and SWP-3A directly from the USGS gage at Reed Street (USGS 04106500; 1948-1958, 1975-1986) Flow frequencies for SWK-2, SWK-4, and SWK-5 were interpolated from SWK-1 and SWK-6 based on respective drainage areas of 1,090, 1,300, and 1,523 square miles.

C Cumulative flow frequency, in the fraction of time on an annual basis, that flow is equal to or less than the upper limit of the flow increment. Based on same data as Column B.

D Average observed PCB concentration for the flow increment. If no samples were collected from a given flow increment, the average PCB concentration from the adjacent flow increments was used.

E Daily average PCB load based on the average flow within the given flow increment and the corresponding average PCB concentration observed within that flow increment. Calculated as the average flow in the flow increment in Column A times the PCB concentration in Column D times 0.002445, where 0.002445 is a conversion factor to produce a load estimate in units of kg/day.

F Annual PCB load if the flow increment were to occur all year. This is the daily PCB load (Column E) times 365 days/year.

G Fraction of the actual total annual PCB load that is attributed to the occurrence of the flow increment in Column A. Calculated by multiplying the fraction of a year a given flow range is expected to occur (Column B) by the annual PCB load expected to occur within that flow increment (Column F). This weights the individual PCB loads by the expected frequency of occurrence. The sum of Column G accounts for 100% of the expected annual flow and PCB load.

TABLE 5-3

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER
1985 - 1988 SURFACE WATER DATA

River Street						
A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 341	0.05	0.05	0.0088	0.0073	2.66	0.133
342 - 402	0.05	0.1	0.0088	0.0079	2.90	0.145
403 - 494	0.1	0.2	0.0088	0.0096	3.50	0.350
495 - 572	0.1	0.3	0.0088	0.0114	4.16	0.416
573 - 650	0.1	0.4	0.013	0.0194	7.09	0.709
651 - 742	0.1	0.5	0.005	0.0085	3.11	0.311
743 - 855	0.1	0.6	0.028	0.0547	19.95	1.995
856 - 1000	0.1	0.7	0.010	0.0215	7.86	0.786
1001 - 1200	0.1	0.8	0.041	0.1096	40.00	4.000
1201 - 1540	0.1	0.9	0.0065	0.0218	7.95	0.795
1541 - 1870	0.05	0.95	0.024	0.1000	36.52	1.826
> 1870	0.05	1	0.0050	0.0249	9.08	0.454
			Total Flow-Stratified PCB Load Estimate (kg) =			12

Michigan Avenue						
A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 382	0.05	0.05	0.0410	0.0383	13.99	0.700
383 - 450	0.05	0.1	0.0410	0.0417	15.22	0.761
451 - 549	0.1	0.2	0.0410	0.0501	18.27	1.827
550 - 635	0.1	0.3	0.0410	0.0594	21.67	2.167
636 - 721	0.1	0.4	0.041	0.0680	24.81	2.481
722 - 822	0.1	0.5	0.019	0.0358	13.08	1.308
823 - 944	0.1	0.6	0.012	0.0259	9.45	0.945
945 - 1100	0.1	0.7	0.005	0.0125	4.56	0.456
1101 - 1311	0.1	0.8	0.022	0.0649	23.67	2.367
1312 - 1670	0.1	0.9	0.0095	0.0346	12.64	1.264
1671 - 2027	0.05	0.95	0.007	0.0328	11.96	0.598
> 2027	0.05	1	0.0050	0.0270	9.84	0.492
			Total Flow-Stratified PCB Load Estimate (kg) =			15

(See notes on page 4)

TABLE 5-3

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER
1985 - 1988 SURFACE WATER DATA

Patterson Street							At Plainwell						
A	B	C	D	E	F	G	A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)	Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 491	0.05	0.05	0.040	0.04	14.02	0.701	<= 491	0.05	0.05	0.097	0.12	42.50	2.125
492 - 575	0.05	0.1	0.040	0.04	15.25	0.762	492 - 575	0.05	0.1	0.097	0.13	46.12	2.306
576 - 694	0.1	0.2	0.040	0.05	18.28	1.828	576 - 694	0.1	0.2	0.097	0.15	54.89	5.489
695 - 802	0.1	0.3	0.040	0.06	21.67	2.167	695 - 802	0.1	0.3	0.097	0.18	64.73	6.473
803 - 906	0.1	0.4	0.010	0.02	6.20	0.620	803 - 906	0.1	0.4	0.097	0.20	73.91	7.391
907 - 1031	0.1	0.5	0.042	0.08	29.61	2.961	907 - 1031	0.1	0.5	0.071	0.17	61.21	6.121
1032 - 1177	0.1	0.6	0.015	0.03	12.10	1.210	1032 - 1177	0.1	0.6	0.082	0.22	81.03	8.103
1178 - 1364	0.1	0.7	0.024	0.06	22.40	2.240	1178 - 1364	0.1	0.7	0.062	0.19	70.29	7.029
1365 - 1603	0.1	0.8	0.012	0.04	13.20	1.320	1365 - 1603	0.1	0.8	0.037	0.13	48.98	4.898
1604 - 2012	0.1	0.9	0.009	0.03	11.54	1.154	1604 - 2012	0.1	0.9	0.012	0.05	19.36	1.936
2013 - 2440	0.05	0.95	0.005	0.02	8.41	0.420	2013 - 2440	0.05	0.95	0.042	0.23	83.44	4.172
> 2440	0.05	1	0.005	0.03	10.03	0.502	> 2440	0.05	1	0.042	0.27	99.49	4.974
Total Flow-Stratified PCB Load Estimate (kg) =						16	Total Flow-Stratified PCB Load Estimate (kg) =						61

(See notes on page 4)

TABLE 5-3

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER
1985 - 1988 SURFACE WATER DATA

M-118						
A	B	C	D	E	F	G
Flow Range (cfs)	Annual Fraction of Time Flow Occurs	Cumulative Occurrence Frequency	Average PCB Concentration Observed (µg/L)	Daily Load For Increment (kg)	Annual Load For Increment (kg)	Fraction of Annual Load For Increment (kg)
<= 606	0.05	0.05	0.057	0.0845	30.84	1.542
607 - 707	0.05	0.[illegible]	0.057	0.0915	33.40	1.670
708 - 847	0.1	0.2	0.057	0.1083	39.53	3.953
848 - 979	0.1	0.3	0.10	0.2232	81.48	8.148
980 - 1102	0.1	0.4	0.13	0.3307	120.72	12.072
1103 - 1253	0.1	0.5	0.109	0.3129	114.21	11.421
1254 - 1425	0.1	0.6	0.15	0.4910	179.23	17.923
1426 - 1643	0.1	0.7	0.15	0.5626	205.34	20.534
1644 - 1913	0.1	0.8	0.087	0.3783	138.06	13.806
1914 - 2375	0.1	0.9	0.10	0.5242	191.32	19.132
2376 - 2879	0.05	0.95	0.10	0.6422	234.41	11.720
> 2879	0.05	1	0.10	0.7654	279.38	13.969
Total Flow-Stratified PCB Load Estimate (kg) =						136

(See notes on page 4)

TABLE 5-3

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
CALCULATIONS FOR THE FLOW-STRATIFIED ESTIMATES OF ANNUAL PCB LOAD IN THE KALAMAZOO RIVER
1985 - 1988 SURFACE WATER DATA

Notes:

A Flow increment for individual PCB load estimate, which was weighted by frequency of occurrence to derive an estimate of annual PCB load.

B Approximate fraction of time, on an annual basis, that flow at the sampling location is within the flow range in Column A. Flow frequencies were based on USGS records: River Street directly from the USGS gage at Comstock (USGS 0410600; 1932-1979, 1984-1993) and directly from the USGS gage at Fennville (USGS 04108500; 1937-1993), Flow frequencies for Plainwell locations (10th Street, Plainwell Dam, and Farmer Street) were interpolated from the Comstock and Fennville gages based on respective drainage areas of 1,010, 1,300, and 1,600 square miles for SWK-1, SWK-4, and SWK-6.

C Cumulative flow frequency, in the fraction of time on an annual basis, that flow is equal to or less than the upper limit of the flow increment. Based on same data as Column B.

D Average observed PCB concentration for the flow increment. If no samples were collected from a given flow increment, the average PCB concentration from the adjacent flow increments was used.

E Daily average PCB load based on the average flow within the given flow increment and the corresponding average PCB concentration observed within that flow increment. Calculated as the average flow in the flow increment in Column A times the PCB concentration in Column D times 0.002445, where 0.002445 is a conversion factor to produce a load estimate in units of kg/day.

F Annual PCB load if the flow increment were to occur all year. This is the daily PCB load (Column E) times 365 days/year.

G Fraction of the actual total annual PCB load that is attributed to the flow increment in Column A calculated by multiplying the fraction of a year a given flow range is expected to occur (Column B) by the annual PCB load expected to occur within that flow increment (Column F). This weights the individual PCB loads by the expected frequency of occurrence. The sum of Column G accounts for 100% of the expected annual flow and PCB load.

TABLE 5-4

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT
KALAMAZOO RIVER FISH PCB HALF-TIME SUMMARY TABLE

Location and Species	Wet-Weight PCB Trends						Lipid-Adjusted PCB Trends				
	1997 PCB (mg/kg)	p-value	r^2	Half-Time (years)			p-value	r^2	Half-Time (years)		
				$t_{1/2}$	LCI	UCI			$t_{1/2}$	LCI	UCI
ABSA 1 Battle Creek (1)											
Carp ≤ 22 inches	0.095	0.068	0.173	12	5.6	--	0.013	0.297	++	++	++
SMB < 16 inches	0.05	0.057	0.178	6.2	3.0	--	0.834	0.002	++	++	++
ABSA 2 Morrow Lake											
Carp ≤ 22 inches	0.25	<0.001	0.474	3.2	2.5	5.9	<0.001	0.270	7.5	5.2	13.0
SMB < 16 inches	0.10	<0.001	0.764	3.1	2.6	4.7	<0.001	0.372	6.6	4.5	13
ABSA 5 Former Plainwell Impoundment											
Carp ≤ 22 inches	1.9	0.007	0.120	11	6.5	39	0.005	0.129	8.9	5.3	28
SMB < 16 inches	0.46	<0.001	0.546	2.7	1.9	5.1	0.41	0.033	25	7.1	--
ABSA 9 Lake Allegan											
Carp ≤ 22 inches	0.72	<0.001	0.159	6.3	4.6	9.1	<0.001	0.175	9.7	7.2	15
SMB < 16 inches	0.50	<0.001	0.409	4.6	3.2	6.6	<0.001	0.428	6.2	4.3	11
W-B Carp (2)	3.9*	<0.001	0.303	5.2	3.6	9.3	<0.001	0.533	3.5	2.8	4.8
ABSA 11 Near New Richmond											
Carp ≤ 22 inches	2.9	0.875	<0.001	++	++	--	0.214	0.026	++	++	++
SMB < 16 inches	0.91	0.436	0.034	15	5.0	--	0.595	0.016	++	++	++
ABSA 13 Near Saugatuck											
Caged Catfish (2)	NA	0.027	0.84	4.4	2.1	21	NA	NA	NA	NA	NA

Notes:
(1) carp were collected from Ceresco Reservoir.
(2) data collected by MDEQ.
-- indicates that predicted slope is not significantly different than zero.
++ indicates that predicted slope is positive.
* indicates 1999 average PCB concentrations was used.
NA indicates not applicable to data set.
SMB indicates smallmouth bass.
LCI indicates lower 95 % confidence interval around the predicted value.
UCI indicates upper 95 % confidence interval around the predicted value.

Figures

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Figures

LEGEND

------- APPROXIMATE BOUNDARY OF FORMER IMPOUNDMENT

NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2400' 4800'

SCALE

DRAFT

FOR STATE AND FEDERAL REVIEW

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

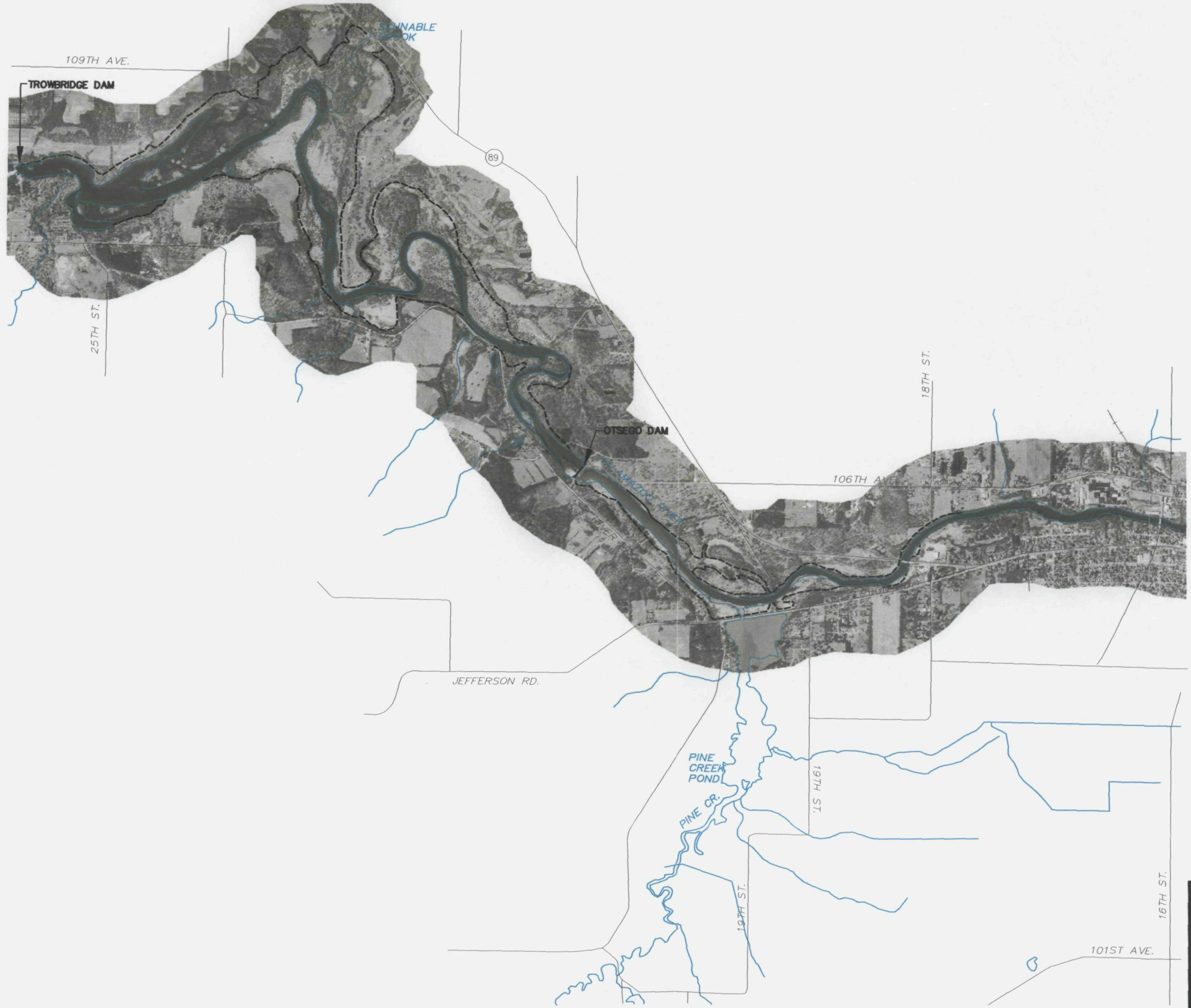
REMEDIAL INVESTIGATION REPORT

FORMER PLAINWELL AND OTSEGO CITY IMPOUNDMENTS

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **1-7**

X: 64524X07.TIF
L: ON=*,OFF=REF
P: 645DJB97.PCP
10/23/00 SYR-54-RLP NES KMD
64524500\OVERVIEW\64524G07.DWG



LEGEND

-------- APPROXIMATE BOUNDARY OF FORMER IMPOUNDMENT

NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2400' 4800'

SCALE

DRAFT

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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

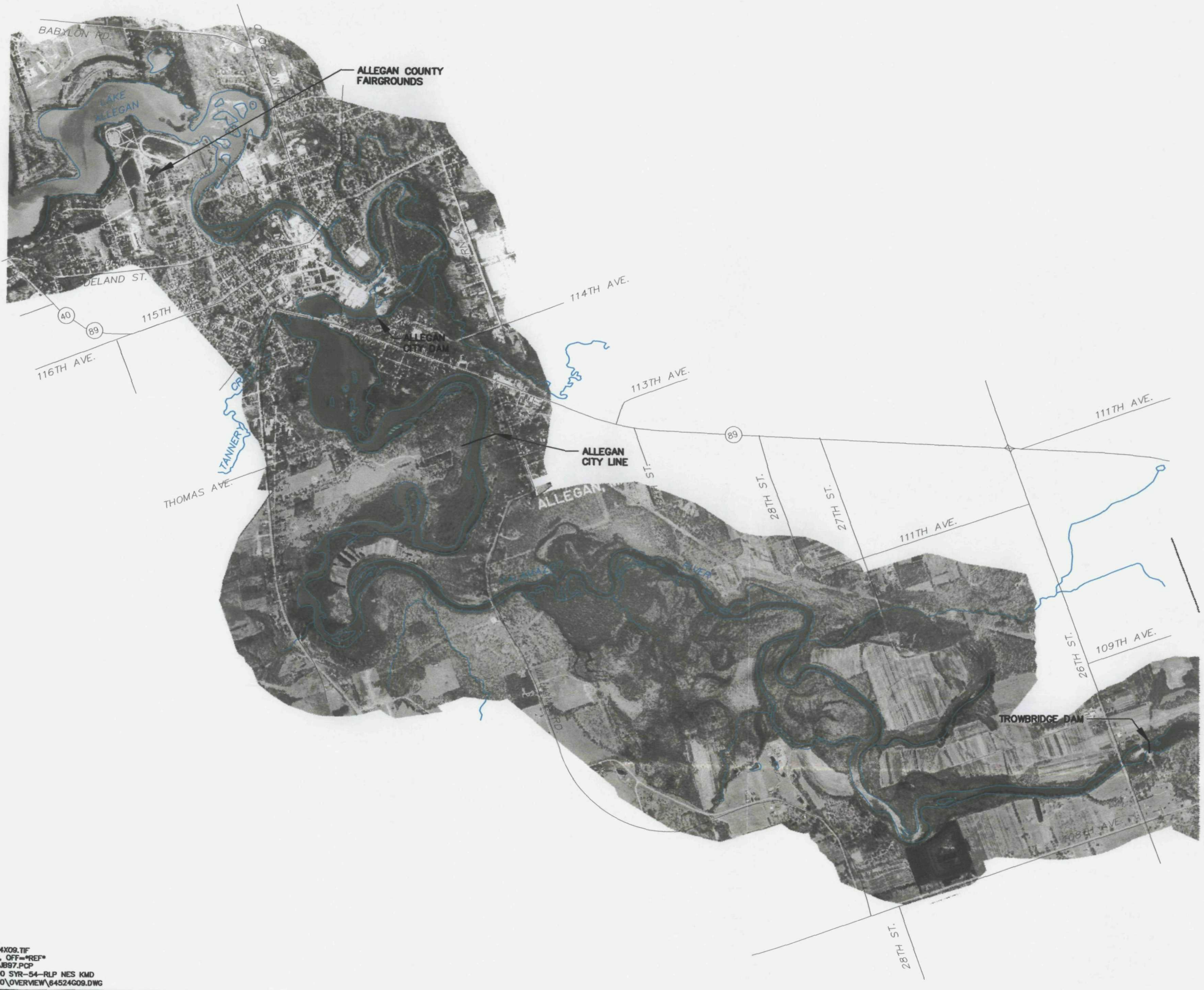
REMEDIAL INVESTIGATION REPORT

FORMER OTSEGO AND FORMER TROWBRIDGE IMPOUNDMENTS

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 1-8

X: 64524X08.TIF
L: ON=*,OFF=REF
P: 645DJB97.PCP
10/23/00 SYR-54-RLP NES KMD
64524500\OVERVIEW\64524G08.DWG



NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2400' 4800'

SCALE

DRAFT

FOR STATE AND FEDERAL REVIEW

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

KALAMAZOO RIVER FROM TROWBRIDGE DAM TO LAKE ALLEGAN

BBL BLASLAND, BOUCK & LEE, INC. *engineers & scientists*

FIGURE **1-9**

X: 64524X09.TIF
L: ON=*, OFF=*REF*
P: 645DJB97.PCP
10/23/00 SYR-54-RLP NES KMD
64524500\OVERVIEW\64524G09.DWG

NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2400' 4800'

SCALE

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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

LAKE ALLEGAN

BBL BLASLAND, BOUCK & LEE, INC. *engineers & scientists*

FIGURE **1-10**

X: 64524X10.TIF
L: ON=*, OFF=*REF*
P: 645DJB97.PCP
10/23/00 SYR-54-RLP NES KMD
64524500\OVERVIEW\64524G10.DWG

NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHI DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/

0 2400' 4800'

SCALE

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FOR STATE AND FEDERAL REVIEW

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

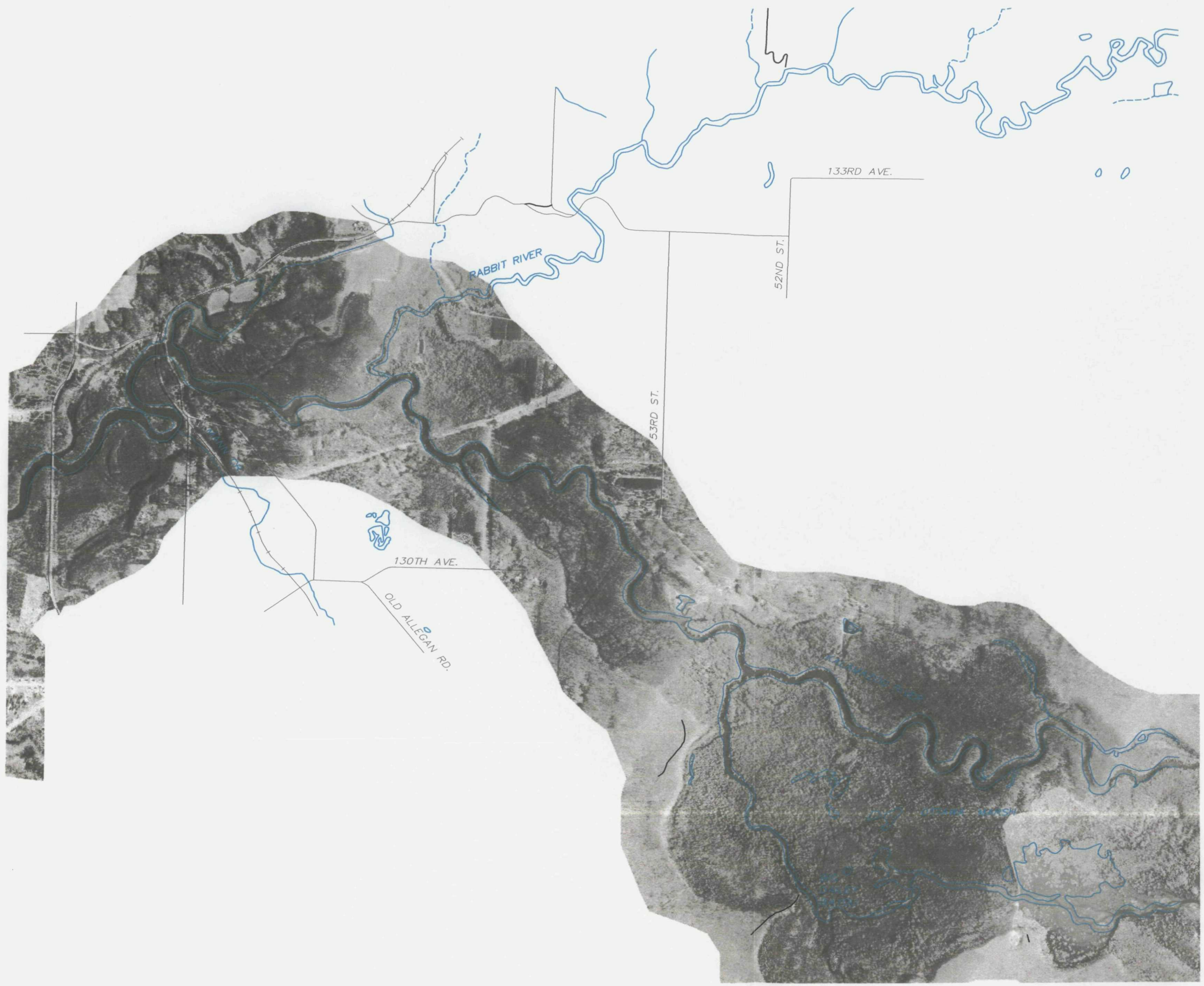
REMEDIAL INVESTIGATION REPORT

KALAMAZOO RIVER FROM LAKE ALLEGAN DAM TO OTTAWA MARSH

BBL BLASLAND, BOUCK & LEE, INC. *engineers & scientists*

FIGURE **1-11**

X: 64524X11.TIF
L: ON=*, OFF=*REF*
P: 645DJB97.PCP
10/23/00 SYR-54-RLP NES KMD
64524500\OVERVIEW\64524G11.DWG



NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2400' 4800'

SCALE

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KALAMAZOO RIVER STUDY GROUP

ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

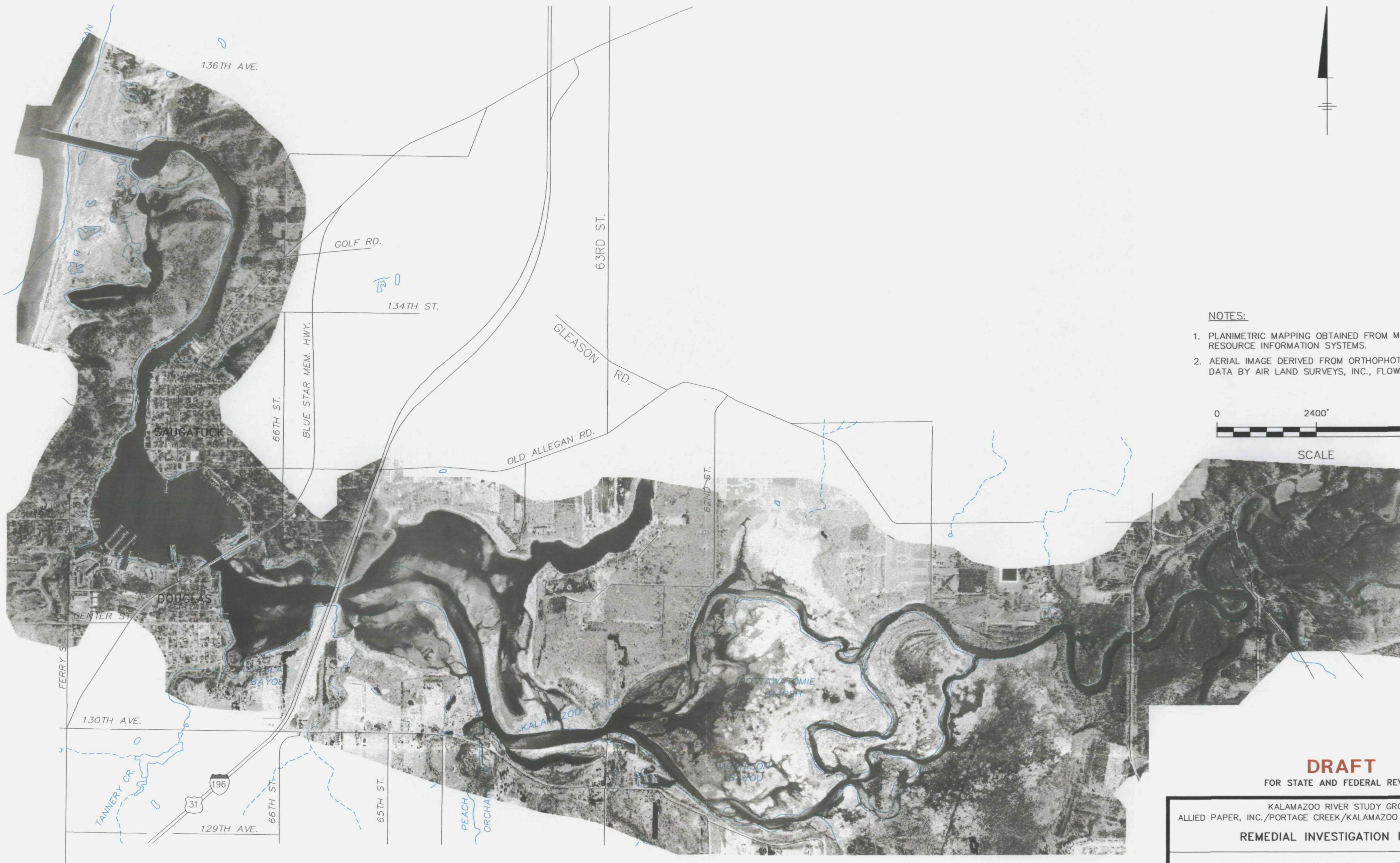
REMEDIAL INVESTIGATION REPORT

KALAMAZOO RIVER FROM OTTAWA MARSH TO THE RABBIT RIVER CONFLUENCE

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **1-12**

X: 64524X12.TIF
L: ON=*, OFF=*REF*
P: 8450JB97.PCP
10/23/00 SYR-54-RLP NES KMD
64524500\OVERVIEW\64524G12.DWG



NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2400' 4800'

SCALE

DRAFT
FOR STATE AND FEDERAL REVIEW

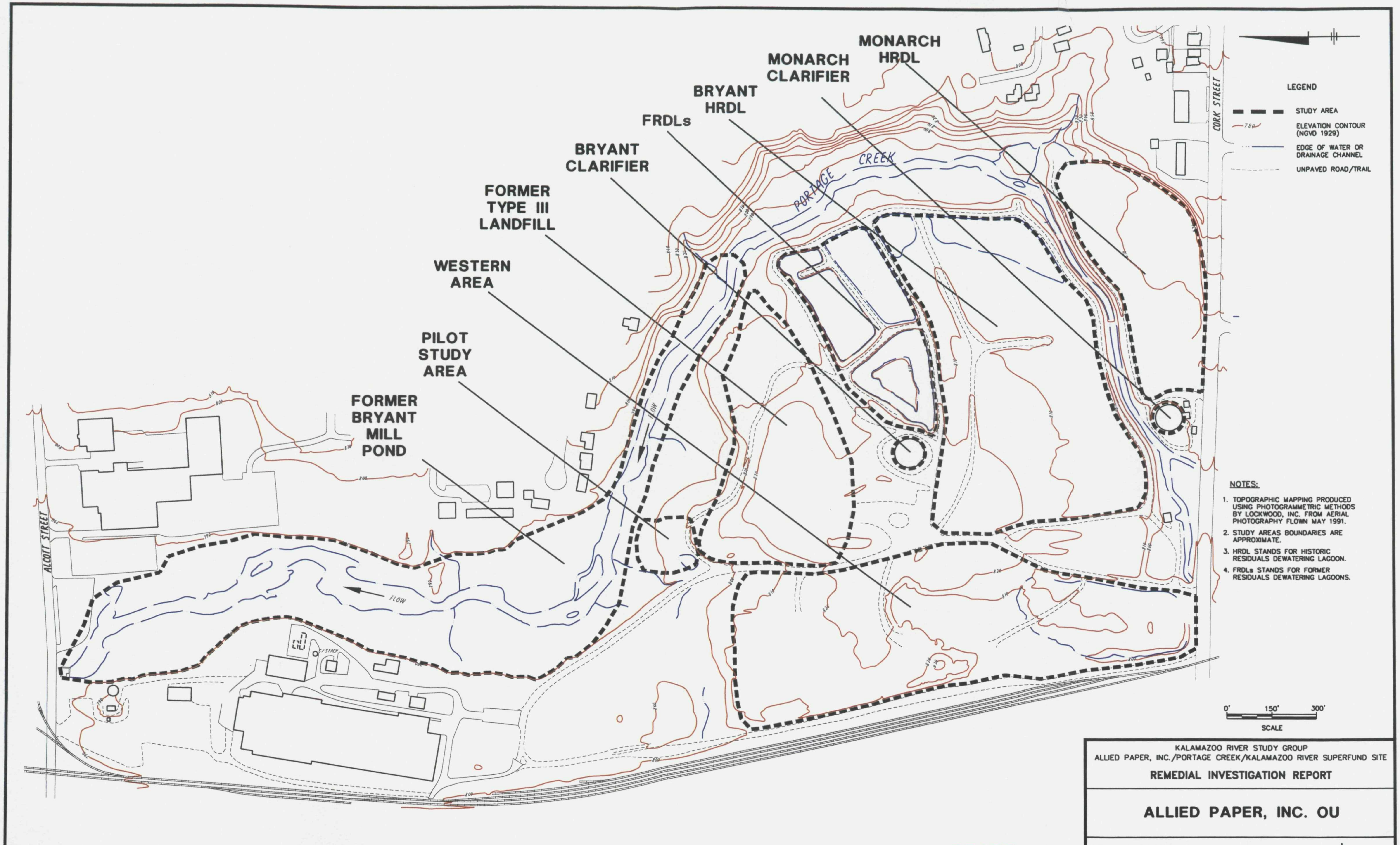
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE
REMEDIAL INVESTIGATION REPORT

POTTAWATOMIE MARSH AND KALAMAZOO LAKE

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 1-13

X: 64524X13.TIF
L: ON=*,OFF=REF
P: 6450JB97.PCP
10/23/00 SYR-54-RLP NES KMD
64524500\OVERVIEW\64524G13.DWG



KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

ALLIED PAPER, INC. OU

L: ON=*,OFF=REF
P: 6450J897.PCP
10/19/00 SYR-54-GMS CBM NES
64524500\OVERVIEW\64524G18.DWG

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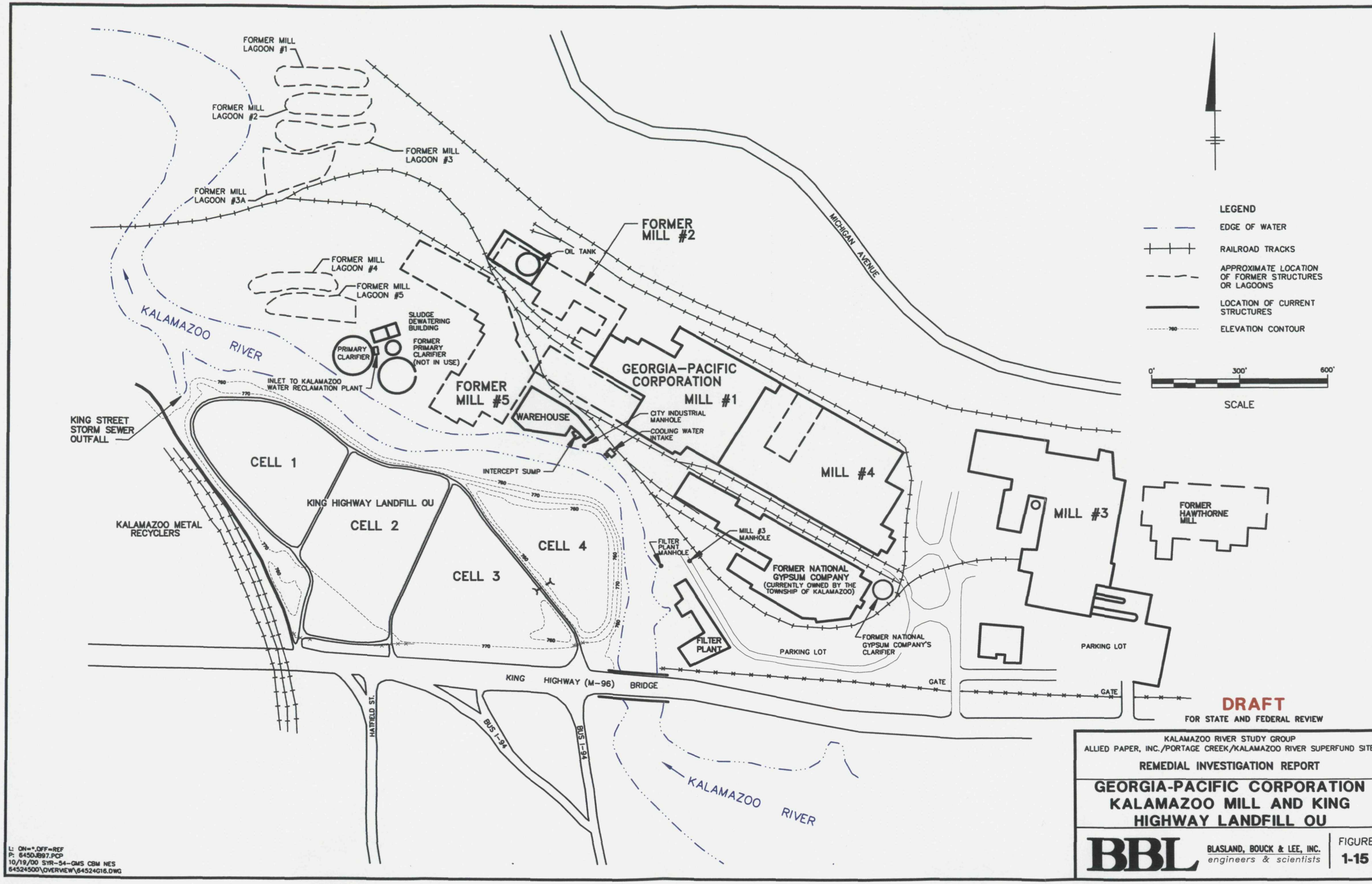
FOR STATE AND FEDERAL REVIEW

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 1-14



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FOR STATE AND FEDERAL REVIEW

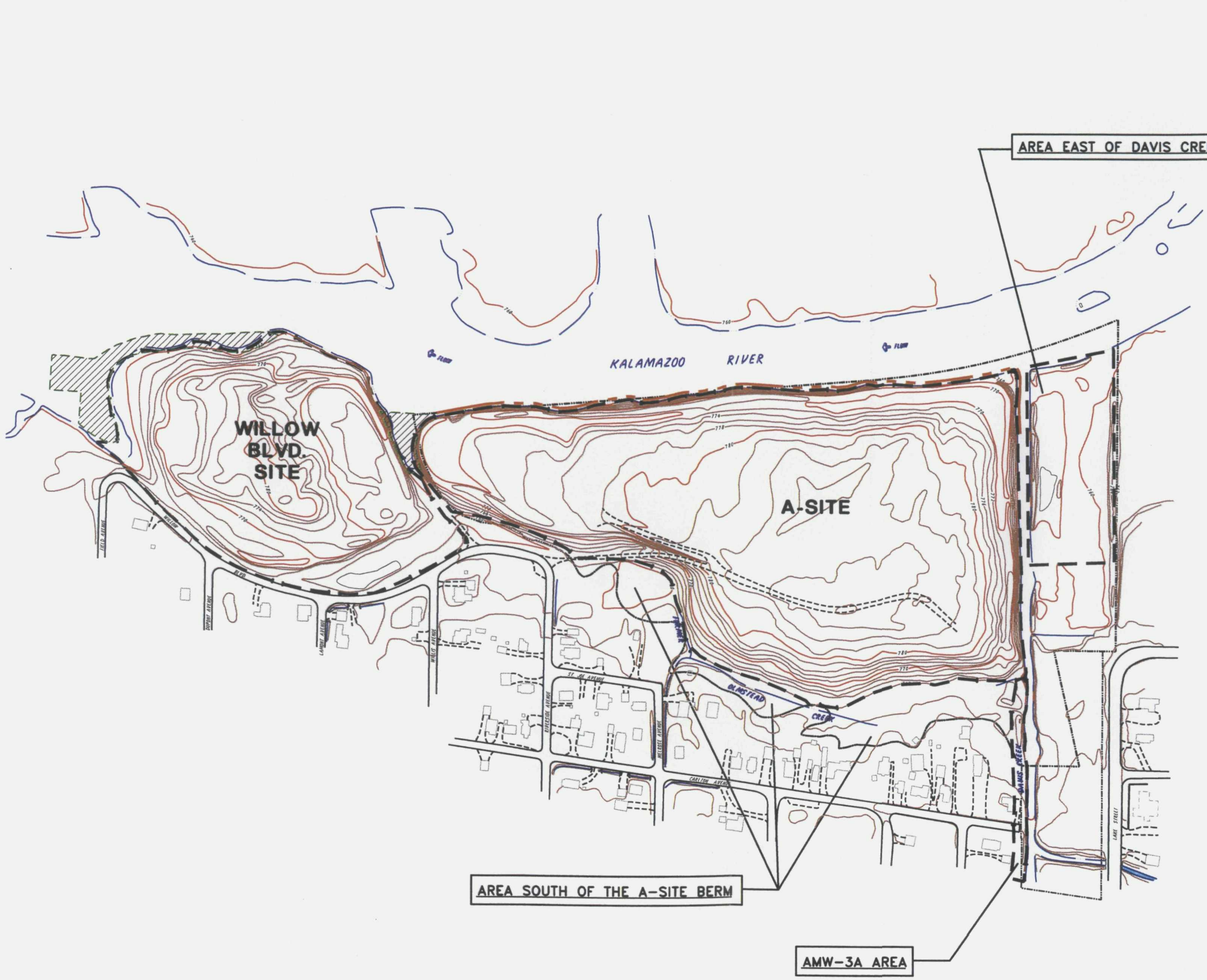
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

GEORGIA-PACIFIC CORPORATION KALAMAZOO MILL AND KING HIGHWAY LANDFILL OU

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 1-15



LEGEND

- 780 — ELEVATION CONTOUR (NGVD 1929)
- EDGE OF WATER OR DRAINAGE CHANNEL
- UNPAVED ROAD/TRAIL
- APPROXIMATE A-SITE BOUNDARY
- GEORGIA-PACIFIC PROPERTY BOUNDARY OUTSIDE OF A-SITE
- APPROXIMATE 1999 EXCAVATION AREAS
- SHEETPILE
- APPROXIMATE BOUNDARY

NOTES:

1. TOPOGRAPHIC MAPPING PRODUCED USING PHOTOGRAMMETRIC METHODS BY LOCKWOOD, INC. FROM AERIAL PHOTOGRAPHY FLOWN APRIL 1991. KALAMAZOO RIVER SOUTH BANK, EAST OF DAVIS CREEK REVISED PER CURRENT CONDITIONS. ADDITIONAL TOPOGRAPHIC CHANGES AFTER APRIL 1991 ARE NOT SHOWN.
2. ALL LOCATIONS ARE APPROXIMATE.

0' 150' 300'
SCALE

L: ON=*,OFF=REF
P: 645DJB97.PCP
10/19/00 SYR-54-GMS CBM NES
64524500\OVERVIEW\64524G19.DWG

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FOR STATE AND FEDERAL REVIEW

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

WILLOW BOULEVARD/A-SITE OU

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 1-16

LEGEND

MW-5A	MONITORING WELL
GMSB-3	SOIL BORING
LH-2/GMSB-2	LEACHATE HEAD WELL – ORIGINAL SOIL BORING
DB-11	DELINEATION BORING
RG-5	RIVER GAUGE
	WETLAND AREA
	FENCE
720	EXISTING MAJOR CONTOUR
	EXISTING MINOR CONTOUR
	TREES/BRUSH
	EDGE OF WATER
	ESTIMATED EXTENT OF RESIDUALS, NOT INCLUDING RESIDUALS THAT MAY BE PRESENT IN THE RIVER SEDIMENTS (DASHED WHERE INFERRED)
	APPROXIMATE WETLAND BOUNDARY (SEE NOTE 3)
	100–YEAR FLOOD ELEVATION (SEE NOTE 3)
	APPROXIMATE PROPERTY LINE (SEE NOTE 4)

NOTES:

1. BASEMAP INFORMATION DIGITIZED FROM FIGURE 2–2 BY GERAGHTY & MILLER INC., ENTITLED "SITE FEATURES MAP", DATED OCTOBER 11, 1994. GERAGHTY & MILLER PLAN BASED ON TOPOGRAPHIC MAPPING PRODUCED USING PHOTOGRAMMETRIC METHODS BY LOCKWOOD, INC. FROM AERIAL PHOTOGRAPHY FLOWN APRIL 17, 1991.
2. RIVER GAUGE LOCATIONS SURVEYED BY BBL, SAMPLE LOCATIONS SURVEYED BY WADE–TRIM.
3. APPROXIMATE WETLAND BOUNDARY AND 100–YEAR FLOOD ELEVATION LIMITS TAKEN FROM FIGURE 2–3 BY GERAGHTY & MILLER INC., ENTITLED "WETLAND AND FLOODPLAIN MAP", DATED OCTOBER 12, 1994.
4. APPROXIMATE PROPERTY LINE TAKEN FROM FIGURE 4–1 BY GERAGHTY & MILLER INC., ENTITLED "CONCEPTUAL CONSOLIDATION PLAN FOR OUTLYING RESIDUALS", DATED FEBRUARY 7, 1994.
5. CONTOUR INTERVAL EQUALS 2 FEET.

0 50' 100'
SCALE

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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

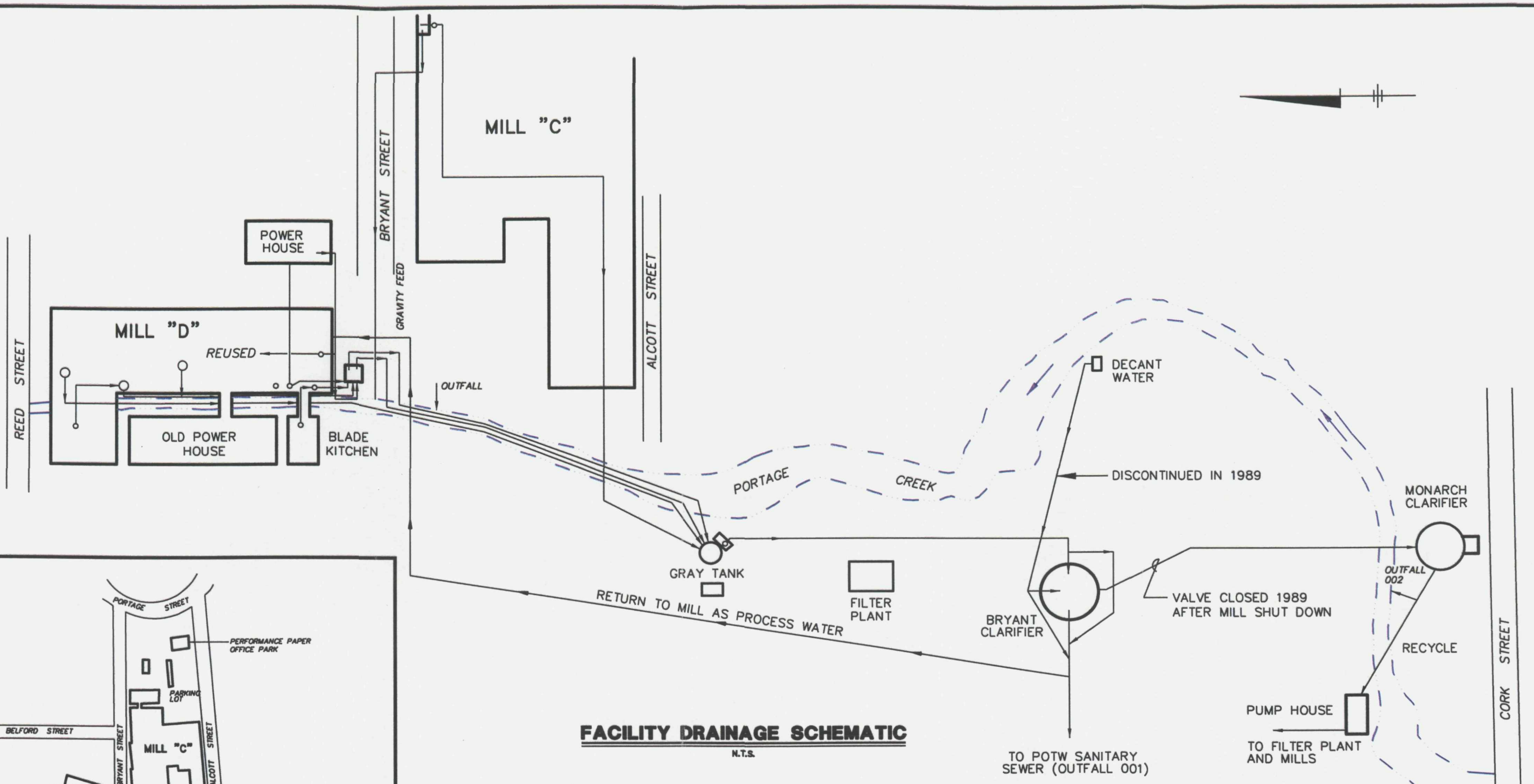
REMEDIAL INVESTIGATION REPORT

12TH STREET LANDFILL OPERABLE UNIT

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

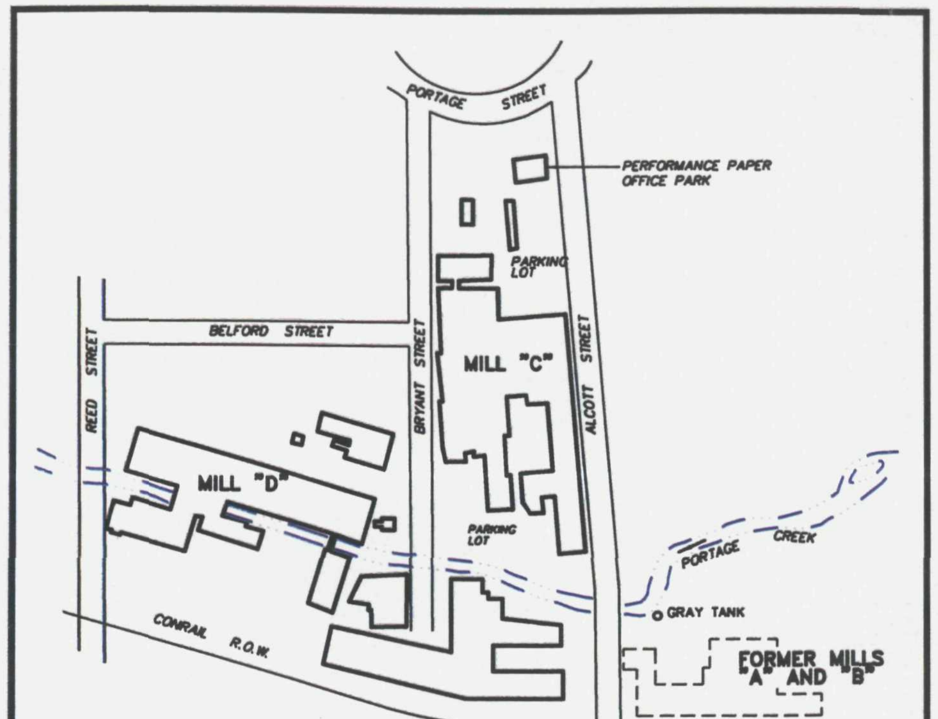
FIGURE 1-17

X: 645906X01.DWG
L: ON=*,OFF=REF
P: STD-PCP/DL
10/19/00 SYR-54-GMS CBM NES
64590685/64590B01.DWG



FACILITY DRAINAGE SCHEMATIC

N.T.S.



SITE PLAN

APPROXIMATE SCALE: 1" = 200'
(SEE ENLARGED FACILITY DRAINAGE SCHEMATIC ABOVE)

L: ON=*,OFF=REF
P: 6450JB97.PCP
10/19/00 SYR-54-GMS CBM NES
64524500\OVERVIEW\64524G14.DWG

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FOR STATE AND FEDERAL REVIEW

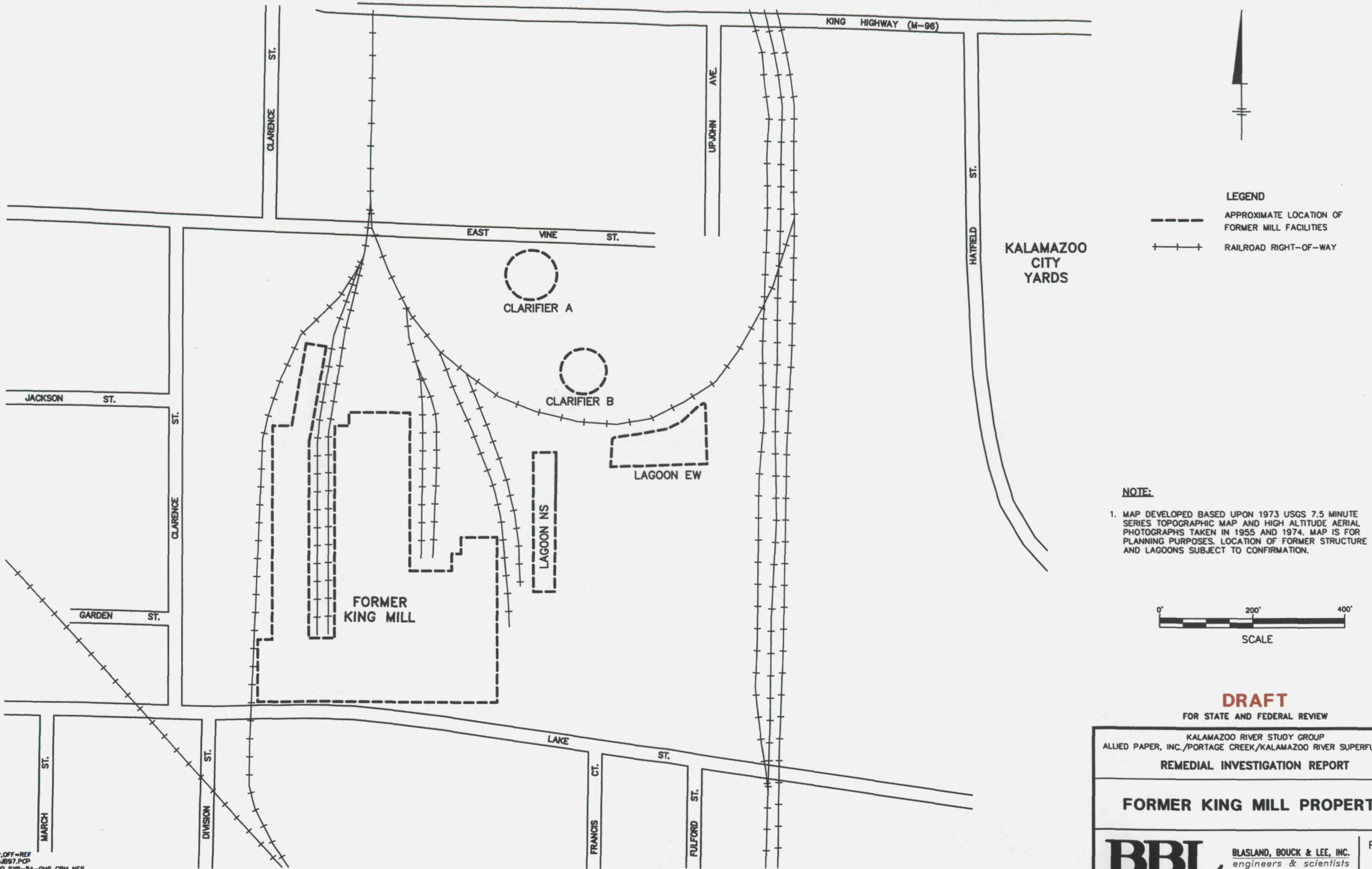
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

FORMER ALLIED PAPER, INC.
BRYANT MILL

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
2-1



NOTE:

1. MAP DEVELOPED BASED UPON 1973 USGS 7.5 MINUTE SERIES TOPOGRAPHIC MAP AND HIGH ALTITUDE AERIAL PHOTOGRAPHS TAKEN IN 1955 AND 1974. MAP IS FOR PLANNING PURPOSES. LOCATION OF FORMER STRUCTURE AND LAGOONS SUBJECT TO CONFIRMATION.

L: ON=*,OFF=REF
P: 6450JB97.PCP
10/19/00 SYR-54-GMS CBM NES
64524500\OVERVIEW\64524G15.DWG

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FOR STATE AND FEDERAL REVIEW

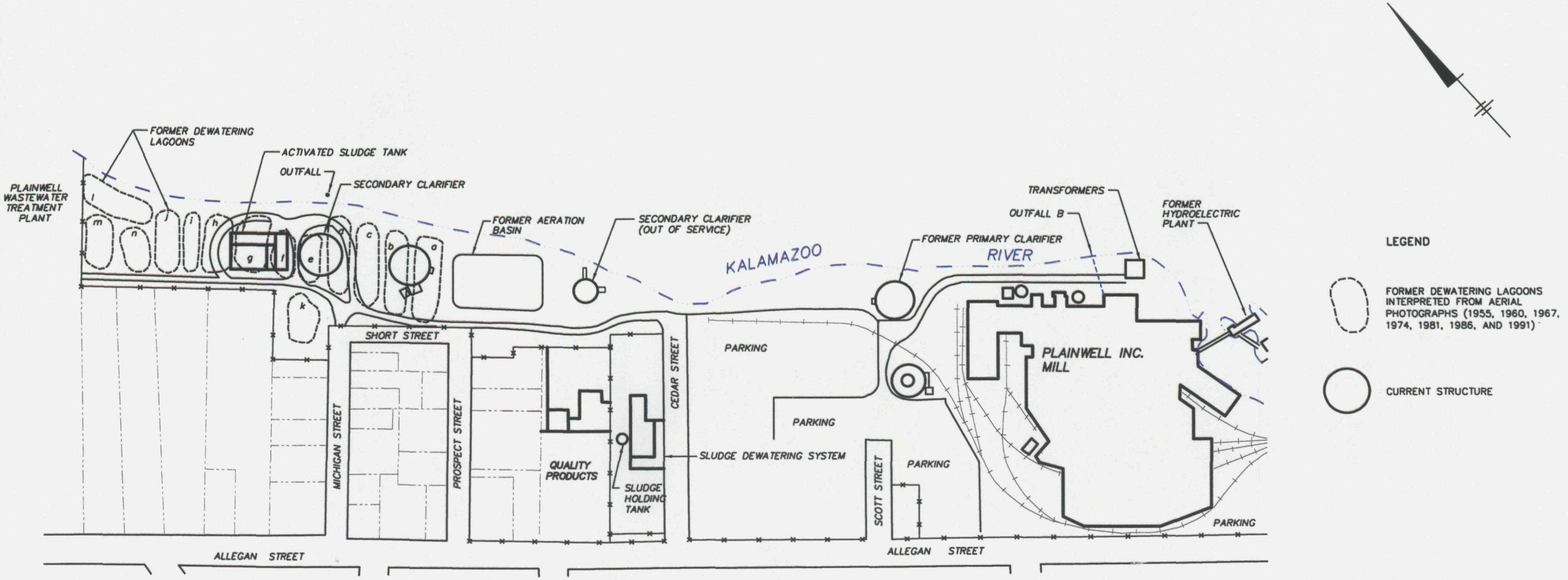
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

FORMER KING MILL PROPERTY

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
2-2



PLAN

SCALE: 1"=250'

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FOR STATE AND FEDERAL REVIEW

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

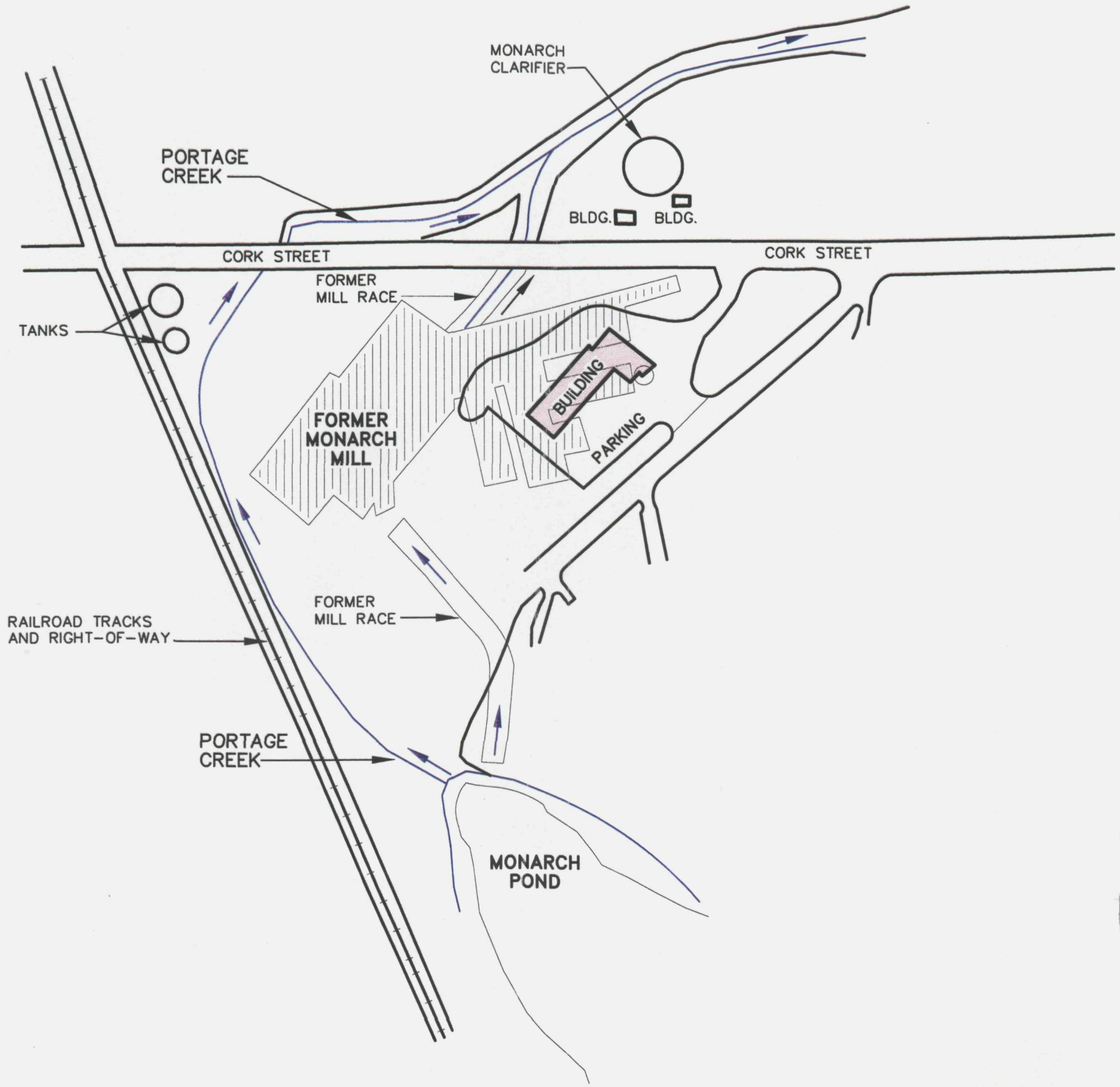
REMEDIAL INVESTIGATION REPORT

PLAINWELL, INC. MILL

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **2-3**

L: ON=*,OFF=REF
P: 6450JB97.PCP
10/19/00 SYR-54-GMS CBM NES
64524500\OVERVIEW\64524G17.DWG



LEGEND

FEATURES PRESENT ONLY ON 1955 AERIAL PHOTOGRAPH

FEATURES PRESENT ON 1991 AERIAL PHOTOGRAPH

0' 200' 400'

APPROXIMATE SCALE: 1" = 200'

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FOR STATE AND FEDERAL REVIEW

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

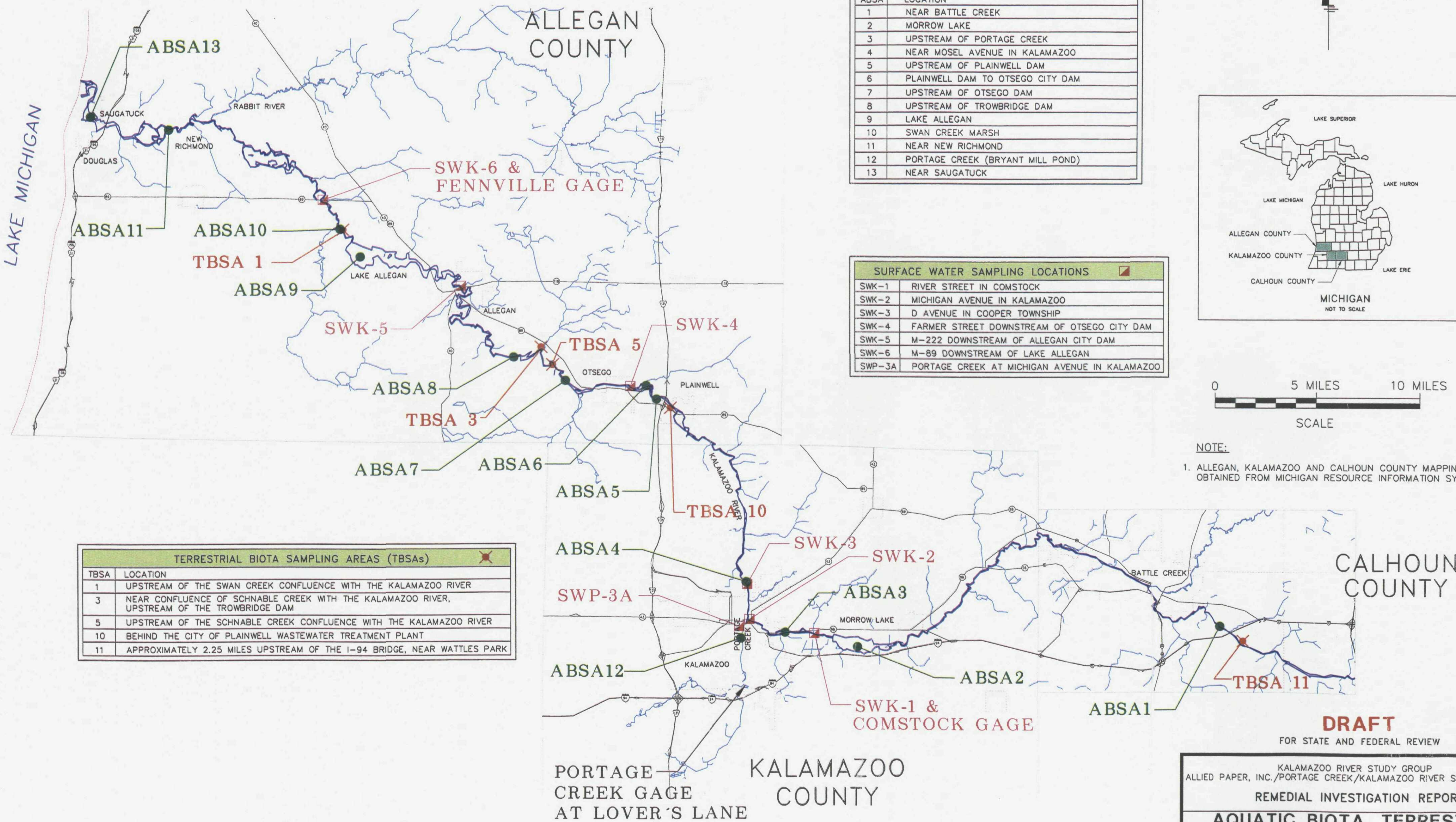
REMEDIAL INVESTIGATION REPORT

FORMER ALLIED PAPER COMPANY MONARCH MILL PROPERTY

BBL BLASLAND, BOUCK & LEE, INC. *engineers & scientists*

FIGURE **2-4**

L: ON=*,OFF=REF
P: 6450JB97.PCP
10/19/00 SYR-54-GMS CBM NES
64524500\OVERVIEW\64524G20.DWG



AQUATIC BIOTA SAMPLING AREAS (ABSAs)

ABSA	LOCATION
1	NEAR BATTLE CREEK
2	MORROW LAKE
3	UPSTREAM OF PORTAGE CREEK
4	NEAR MOSEL AVENUE IN KALAMAZOO
5	UPSTREAM OF PLAINWELL DAM
6	PLAINWELL DAM TO OTSEGO CITY DAM
7	UPSTREAM OF OTSEGO DAM
8	UPSTREAM OF TROWBRIDGE DAM
9	LAKE ALLEGAN
10	SWAN CREEK MARSH
11	NEAR NEW RICHMOND
12	PORTAGE CREEK (BRYANT MILL POND)
13	NEAR SAUGATUCK

SURFACE WATER SAMPLING LOCATIONS

SWK-1	RIVER STREET IN COMSTOCK
SWK-2	MICHIGAN AVENUE IN KALAMAZOO
SWK-3	D AVENUE IN COOPER TOWNSHIP
SWK-4	FARMER STREET DOWNSTREAM OF OTSEGO CITY DAM
SWK-5	M-222 DOWNSTREAM OF ALLEGAN CITY DAM
SWK-6	M-89 DOWNSTREAM OF LAKE ALLEGAN
SWP-3A	PORTAGE CREEK AT MICHIGAN AVENUE IN KALAMAZOO

TERRESTRIAL BIOTA SAMPLING AREAS (TBSAs)

TBSA	LOCATION
1	UPSTREAM OF THE SWAN CREEK CONFLUENCE WITH THE KALAMAZOO RIVER
3	NEAR CONFLUENCE OF SCHNABLE CREEK WITH THE KALAMAZOO RIVER, UPSTREAM OF THE TROWBRIDGE DAM
5	UPSTREAM OF THE SCHNABLE CREEK CONFLUENCE WITH THE KALAMAZOO RIVER
10	BEHIND THE CITY OF PLAINWELL WASTEWATER TREATMENT PLANT
11	APPROXIMATELY 2.25 MILES UPSTREAM OF THE I-94 BRIDGE, NEAR WATTLES PARK

NOTE:

1. ALLEGAN, KALAMAZOO AND CALHOUN COUNTY MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEM.

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X: NONE
L: ON=*;OFF=REF
P: STD-PCP/BL
10/27/00 SYR-54-AK NES KMD
64524500/OVERVIEW/64524G28.DWG

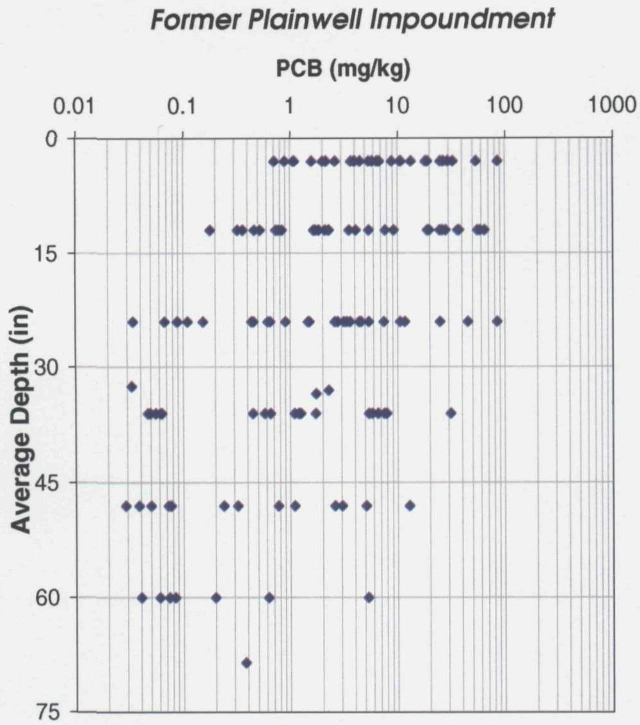
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

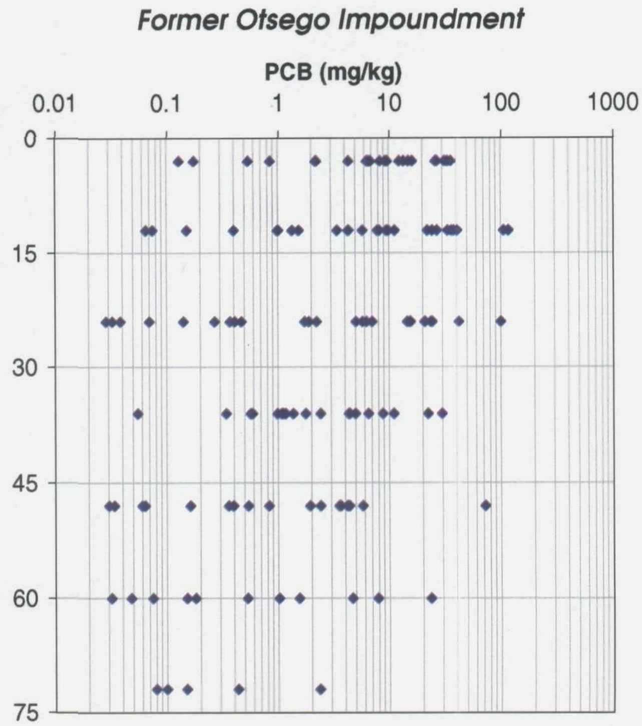
REMEDIAL INVESTIGATION REPORT

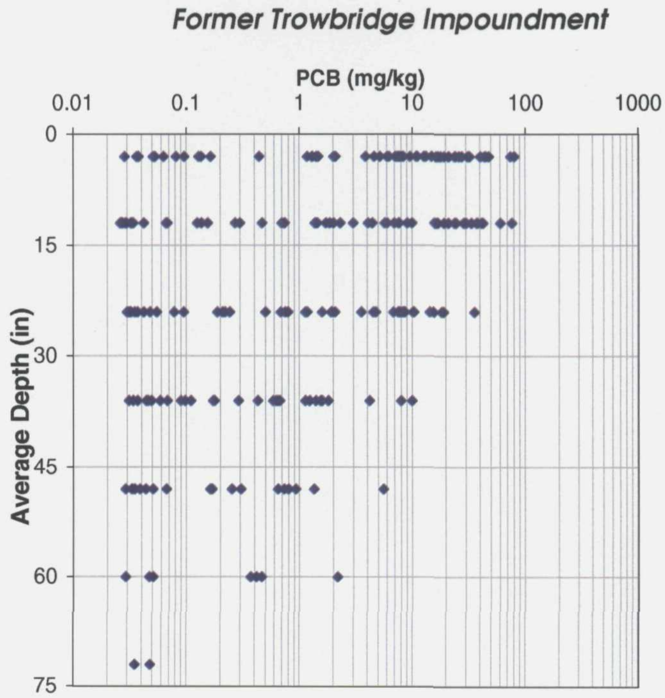
AQUATIC BIOTA, TERRESTRIAL BIOTA, AND SURFACE WATER SAMPLING LOCATIONS

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 2-5







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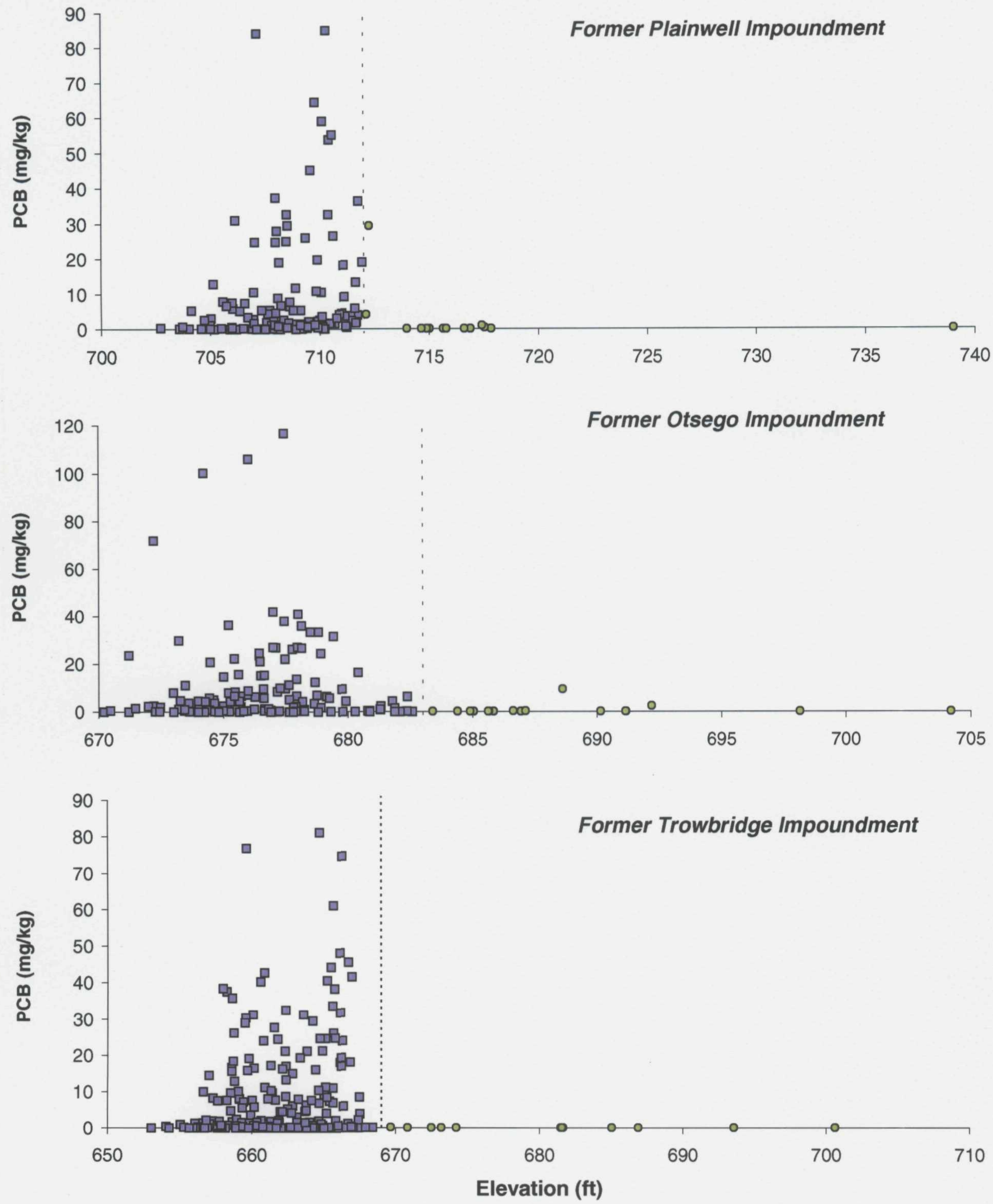
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

RELATIONSHIP OF PCB CONCENTRATION AND SAMPLE DEPTH - FORMER IMPOUNDMENT EXPOSED SEDIMENT

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 4-1



LEGEND

■ Within the Former Impoundment

● Outside of the Former Impoundment

······ Pre-drawdown normal pool elevation

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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

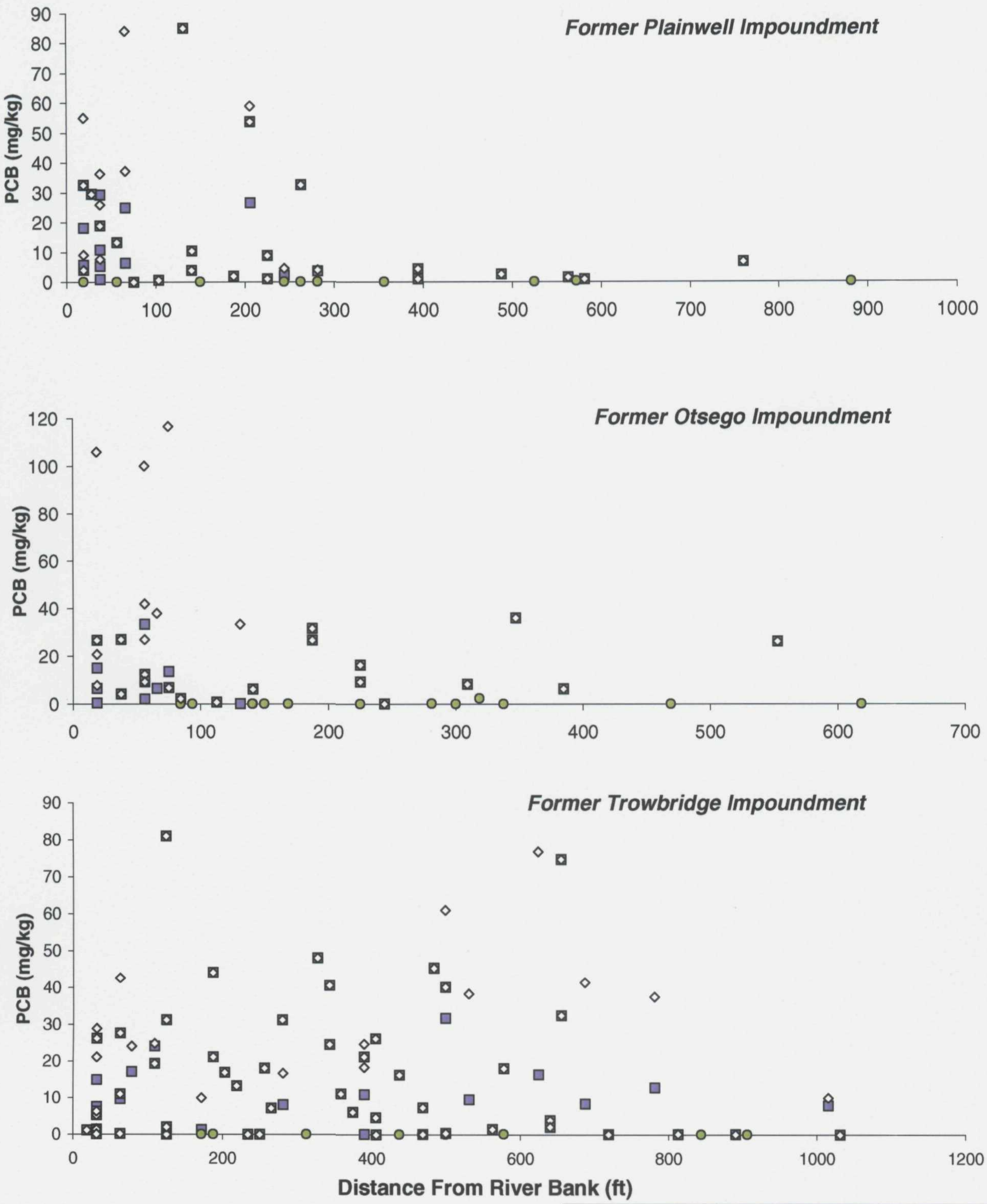
REMEDIAL INVESTIGATION REPORT

EXPOSED SEDIMENT AND SOIL PCB LEVELS IN AND NEAR THE FORMER IMPOUNDMENTS IN RELATION TO ELEVATION AND FORMER IMPOUNDMENT POOL ELEVATION

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-2

DMP_kzdmpfrmimpFIGS.xls_4-2



LEGEND

- ■ Surface PCB Concentration Within Former Impoundments
- ● Surface PCB Concentration Outside the Former Impoundments
- ◇ Maximum PCB Concentration in Core

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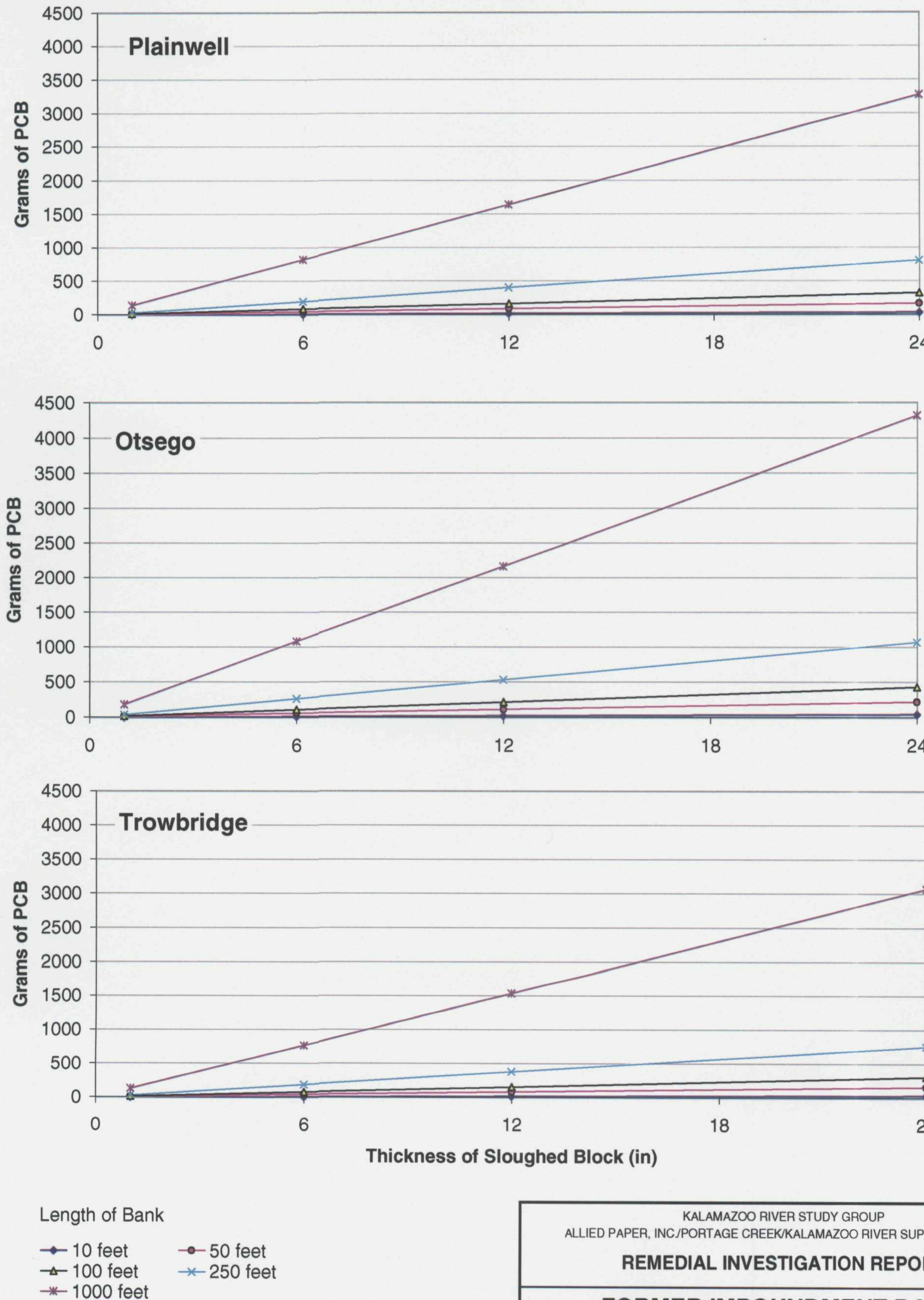
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

RELATIONSHIP OF FORMER IMPOUNDMENT TRANSECT PCB CONCENTRATION AND DISTANCE FROM RIVER BANK

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-3



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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

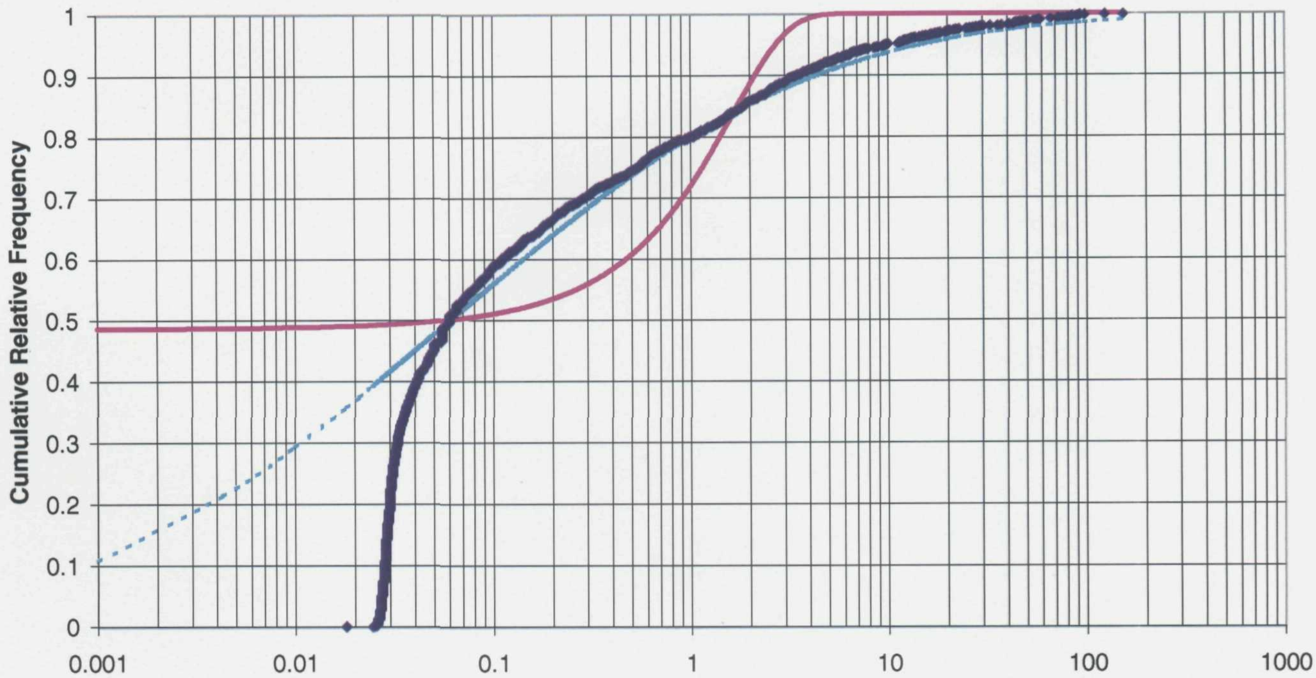
REMEDIAL INVESTIGATION REPORT

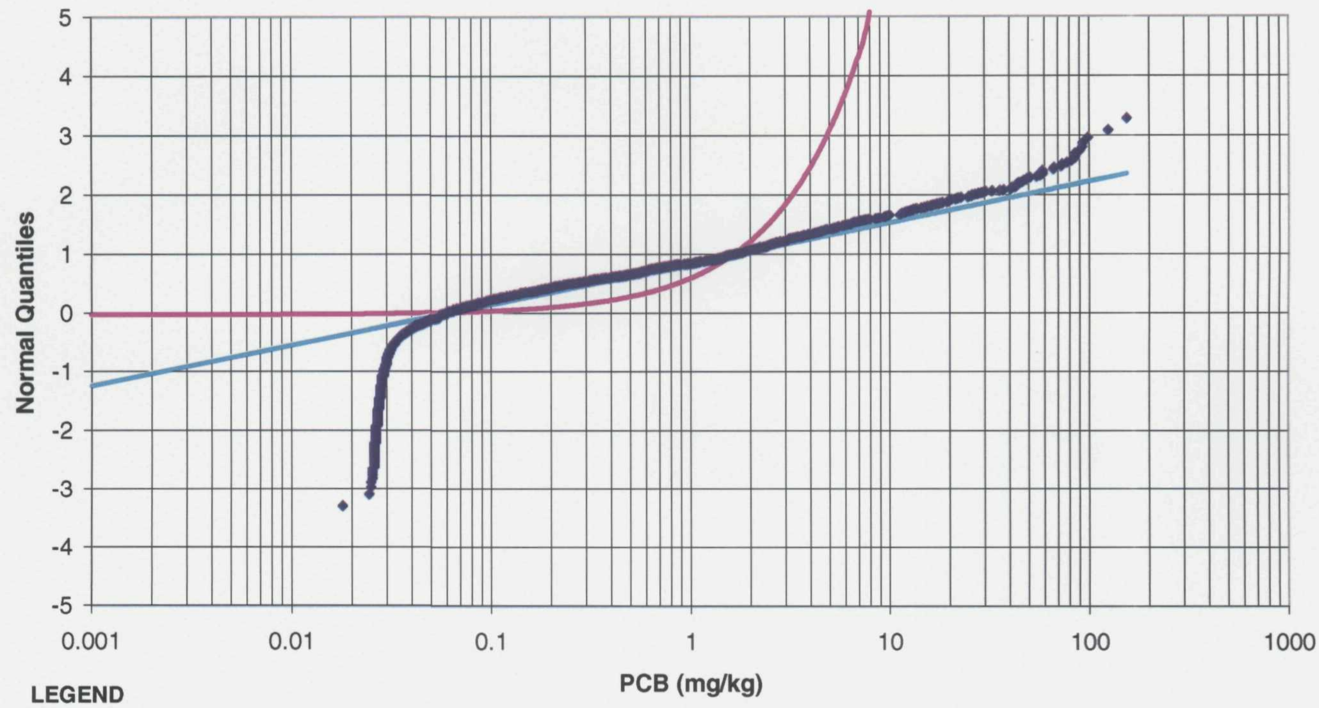
FORMER IMPOUNDMENT BANK STREAMBANK EROSION ESTIMATES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-4

MJS_k fmrimp erosion.xls_4-4





LEGEND

- ◆ Actual Distribution
- — Normal Distribution
- — Lognormal Distribution

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NOTE:
Normal and lognormal population distrubutions use the median as a represenation of the mean and the difference between the median and 84th percentile to represent one standard deviation.

KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

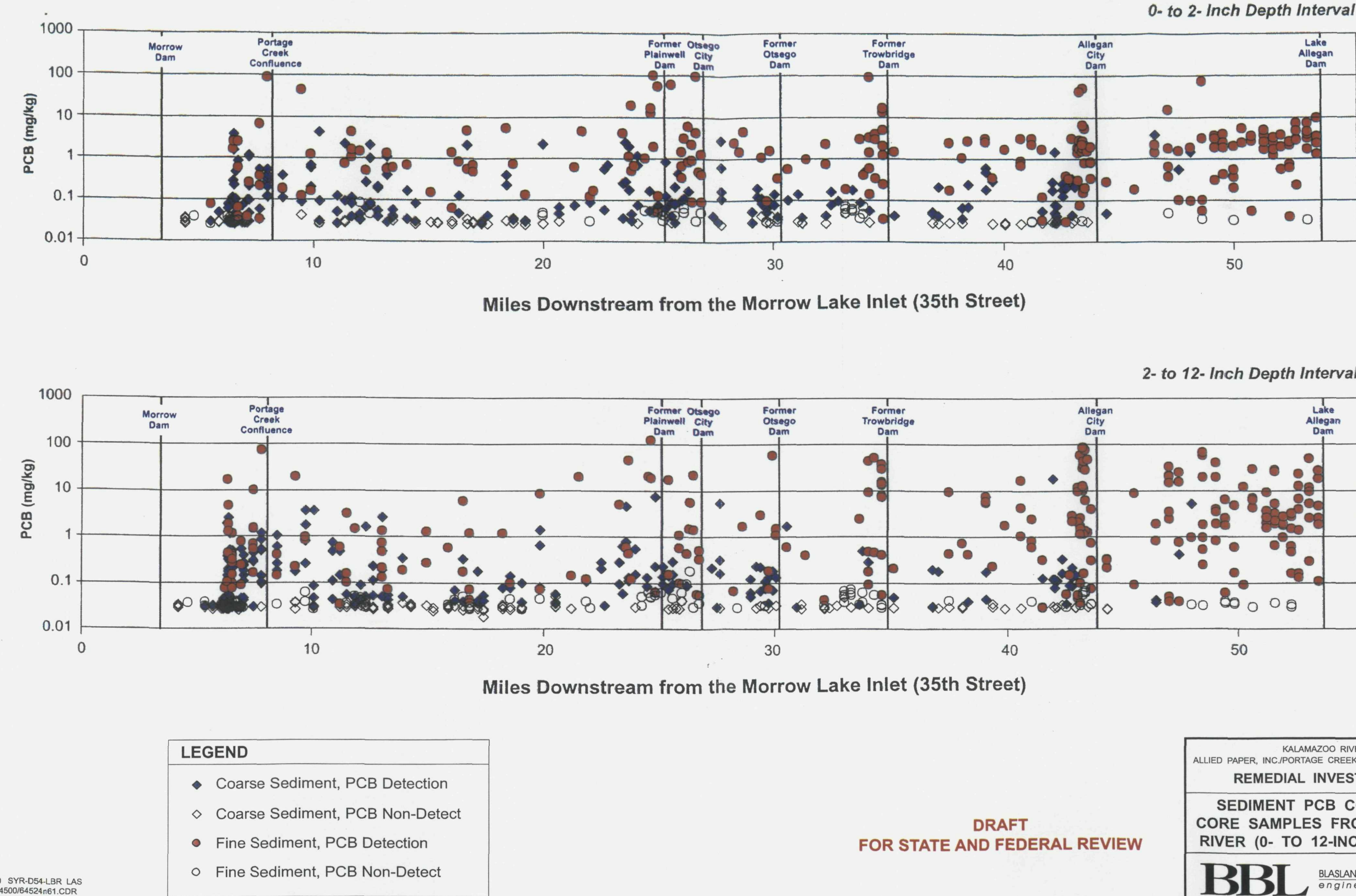
REMEDIAL INVESTIGATION REPORT

COMPARISON OF NORMAL AND LOGNORMAL POPULATION DISTRIBUTIONS TO THE ACTUAL SEDIMENT PCB DISTRIBUTION

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-5

MJS_kzlognormal.xls_4-5



10/00 SYR-D54-LBR LAS
64524500/64524n61.CDR

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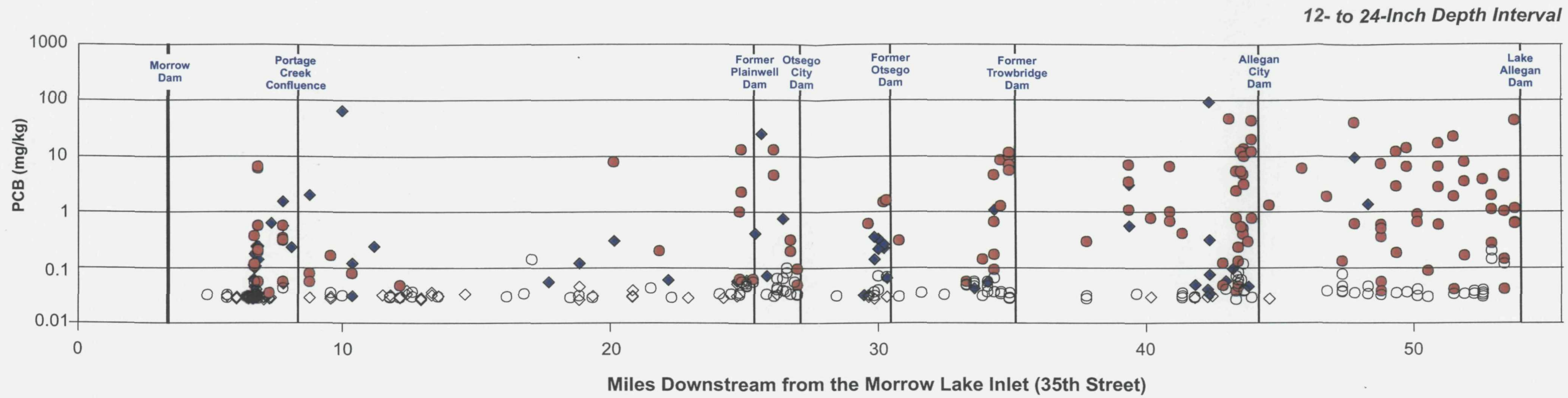
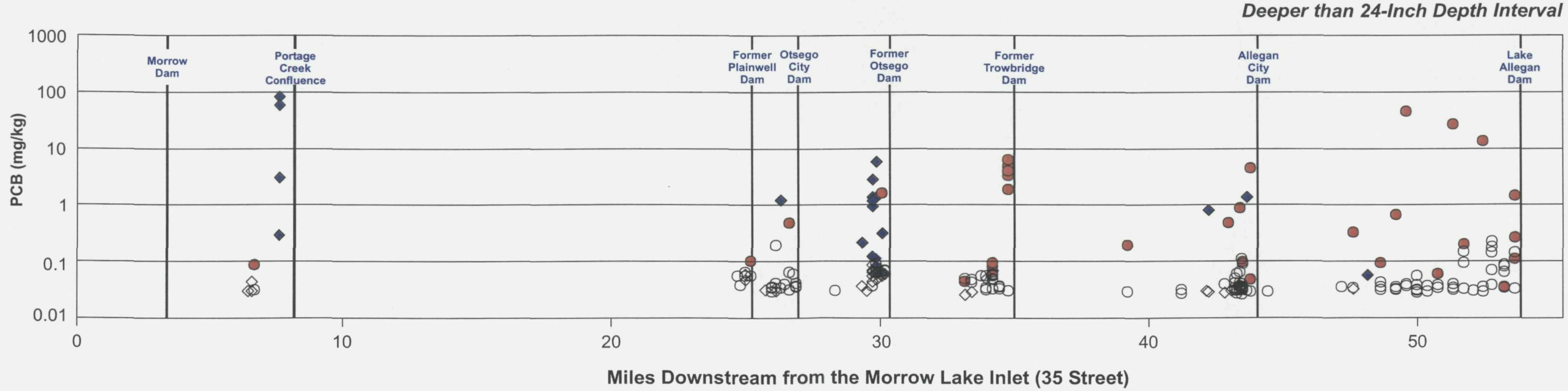
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE
REMEDIAL INVESTIGATION REPORT

SEDIMENT PCB CONCENTRATION IN CORE SAMPLES FROM THE KALAMAZOO RIVER (0- TO 12-INCH DEPTH INTERVAL)

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE
4-6





LEGEND

- ◆ Coarse Sediment, PCB Detection
- ◇ Coarse Sediment, PCB Non-Detect
- ● Fine Sediment, PCB Detection
- ○ Fine Sediment, PCB Non-Detect

10/00 SYR-D54-LBR LAS
64524500/64524n35.CDR

DRAFT
FOR STATE AND FEDERAL REVIEW

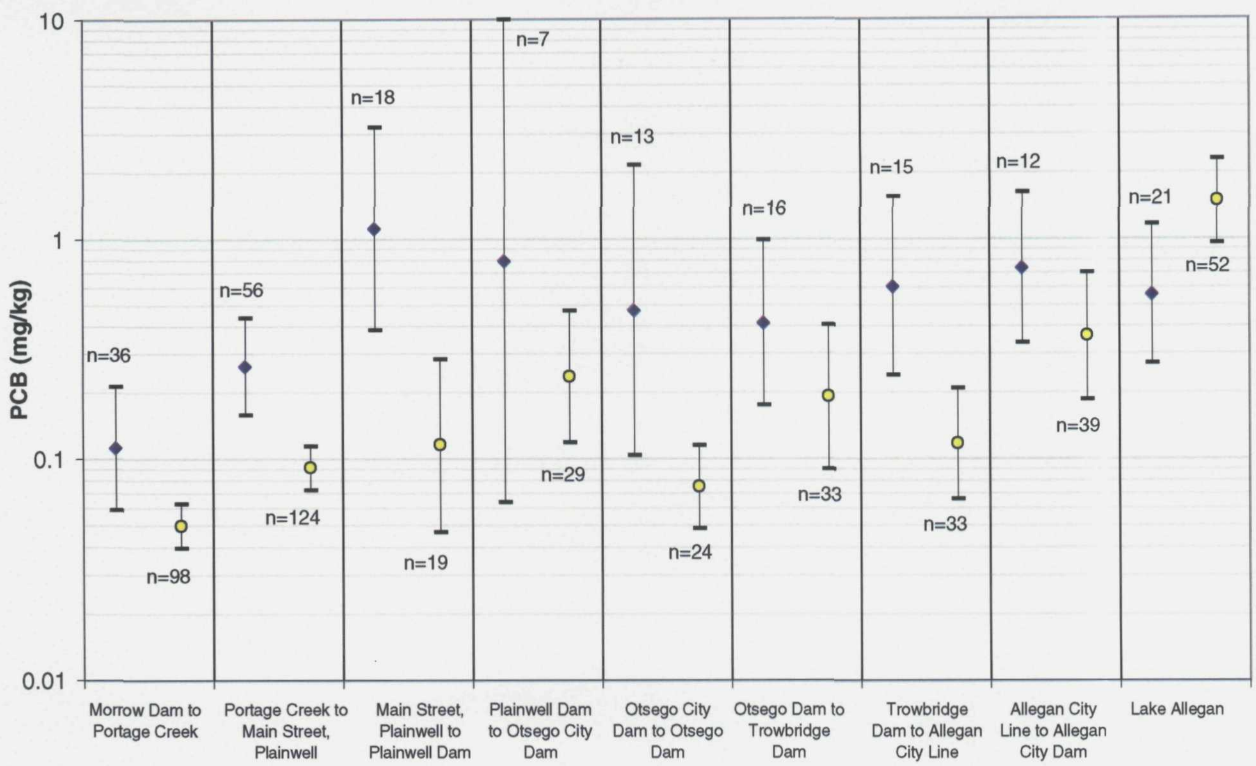
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

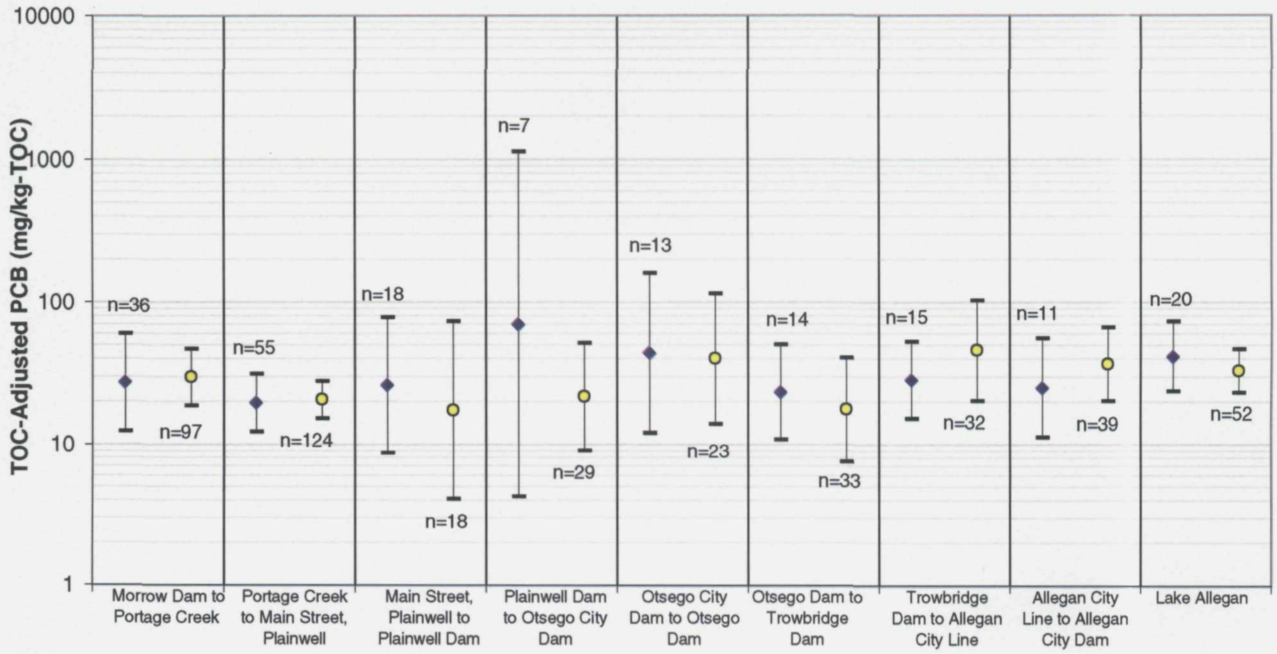
REMEDIAL INVESTIGATION REPORT

SEDIMENT PCB CONCENTRATION IN CORE SAMPLES FROM THE KALAMAZOO RIVER (DEEPER THAN 12 INCHES)

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE
4-7





LEGEND

- Channel
- Near Bank

n = Number of samples

Upper 95% confidence limit
Geometric Mean Concentration
Lower 95% confidence limit

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NOTE:
Use of geometric mean concentration due to log-normality of data, which was determined by the Shaprio-Wilk Test (n<50) and Shapiro-Francia Test (n>50) (USEPA, 1992).

KALAMAZOO RIVER STUDY GROUP
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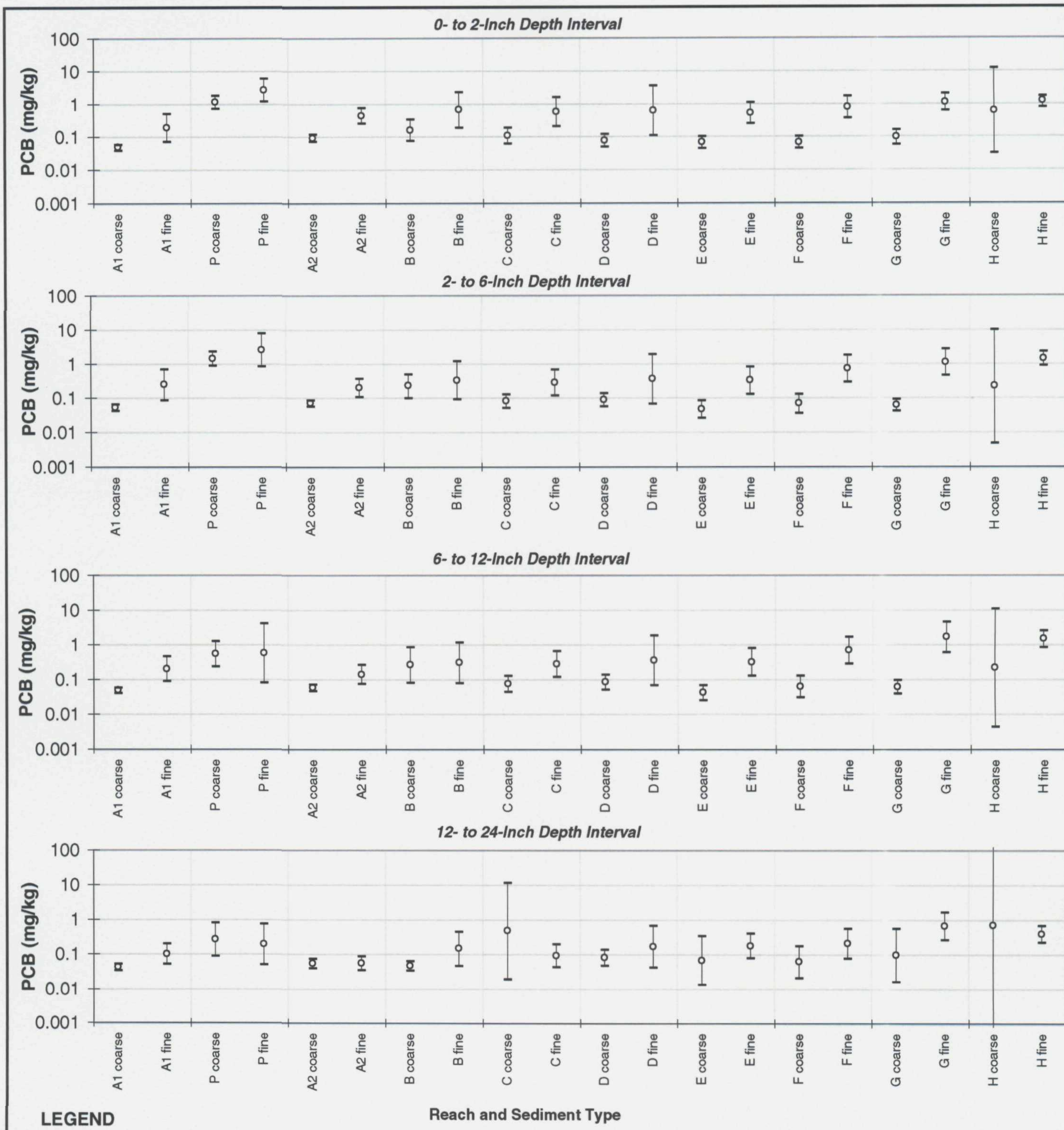
REMEDIAL INVESTIGATION REPORT

COMPARISON OF GEOMETRIC MEAN PCB AND TOC-ADJUSTED PCB CONCENTRATIONS IN NEAR BANK AND CHANNEL SURFACE SEDIMENTS

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 4-8

DMP_bnkchldat.xls_4-8



LEGEND

Upper 95% confidence limit

Geometric Mean Concentration

Lower 95% confidence limit

A1: Morrow Dam to Portage Creek
P: Portage Creek
A2: Portage Creek to Main Street, Plainwell
B: Main Street, Plainwell to Plainwell Dam
C: Plainwell Dam to Otsego City Dam
D: Otsego City Dam to Otsego Dam
E: Otsego Dam to Trowbridge Dam
F: Trowbridge Dam to Allegan City Line
G: Allegan City Line to Allegan City Dam
H: Lake Allegan

To provide uniform sample intervals, a depth weighted average was used when the actual sample interval differed from those above.

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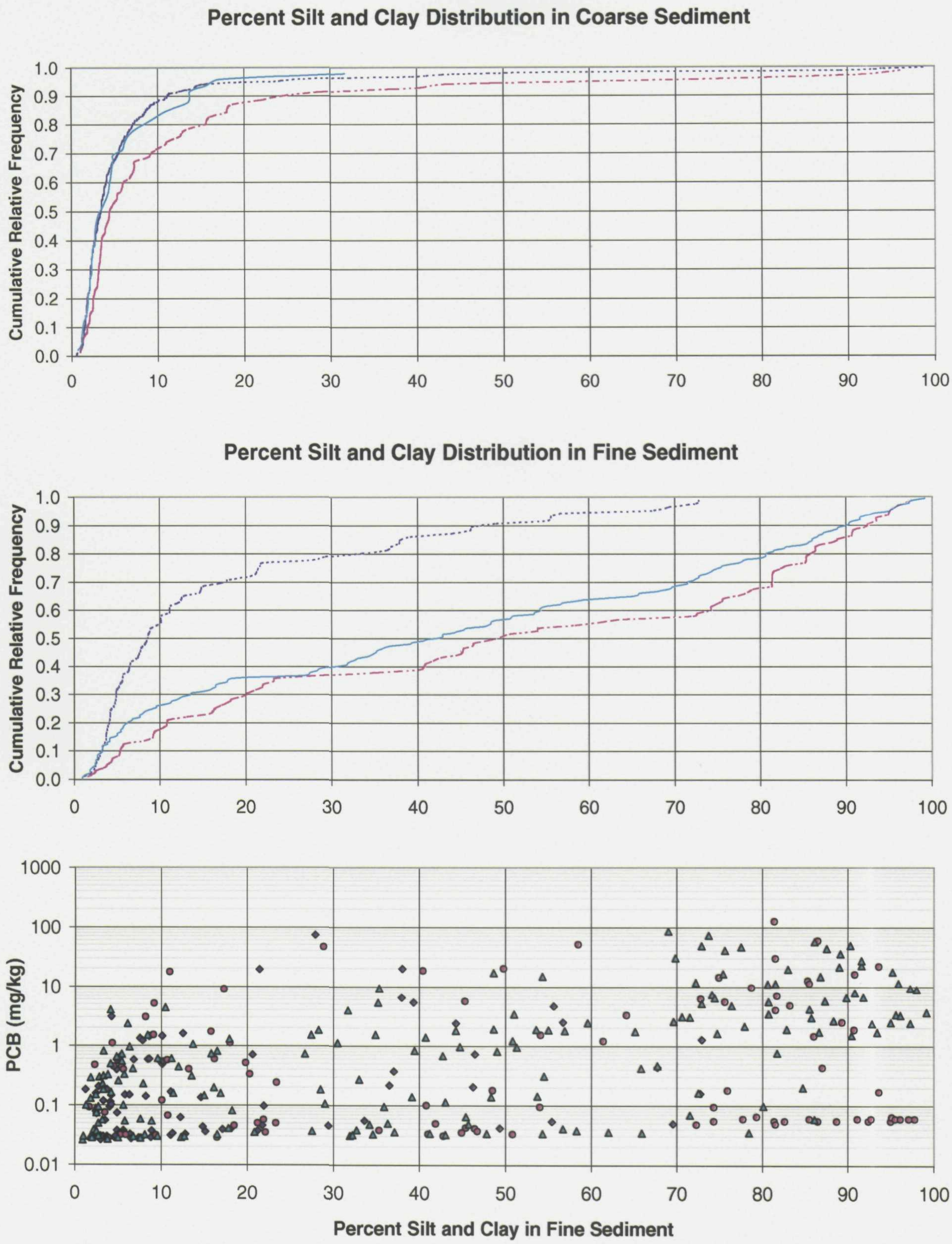
REMEDIAL INVESTIGATION REPORT

GEOMETRIC MEAN PCB CONCENTRATIONS AND CONFIDENCE INTERVALS BY REACH AND SEDIMENT CLASSIFICATION FOR 1993 FROZEN CORES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-9

MJS_RIGMean.xls_4-9



LEGEND

- Morrow Dam to Main Street, Plainwell
- Main Street, Plainwell to Trowbridge Dam
- Trowbridge Dam to Lake Allegan Dam

- ◆ Morrow Dam to Main Street, Plainwell
- ● Main Street, Plainwell to Trowbridge Dam
- ▲ Trowbridge Dam to Lake Allegan Dam

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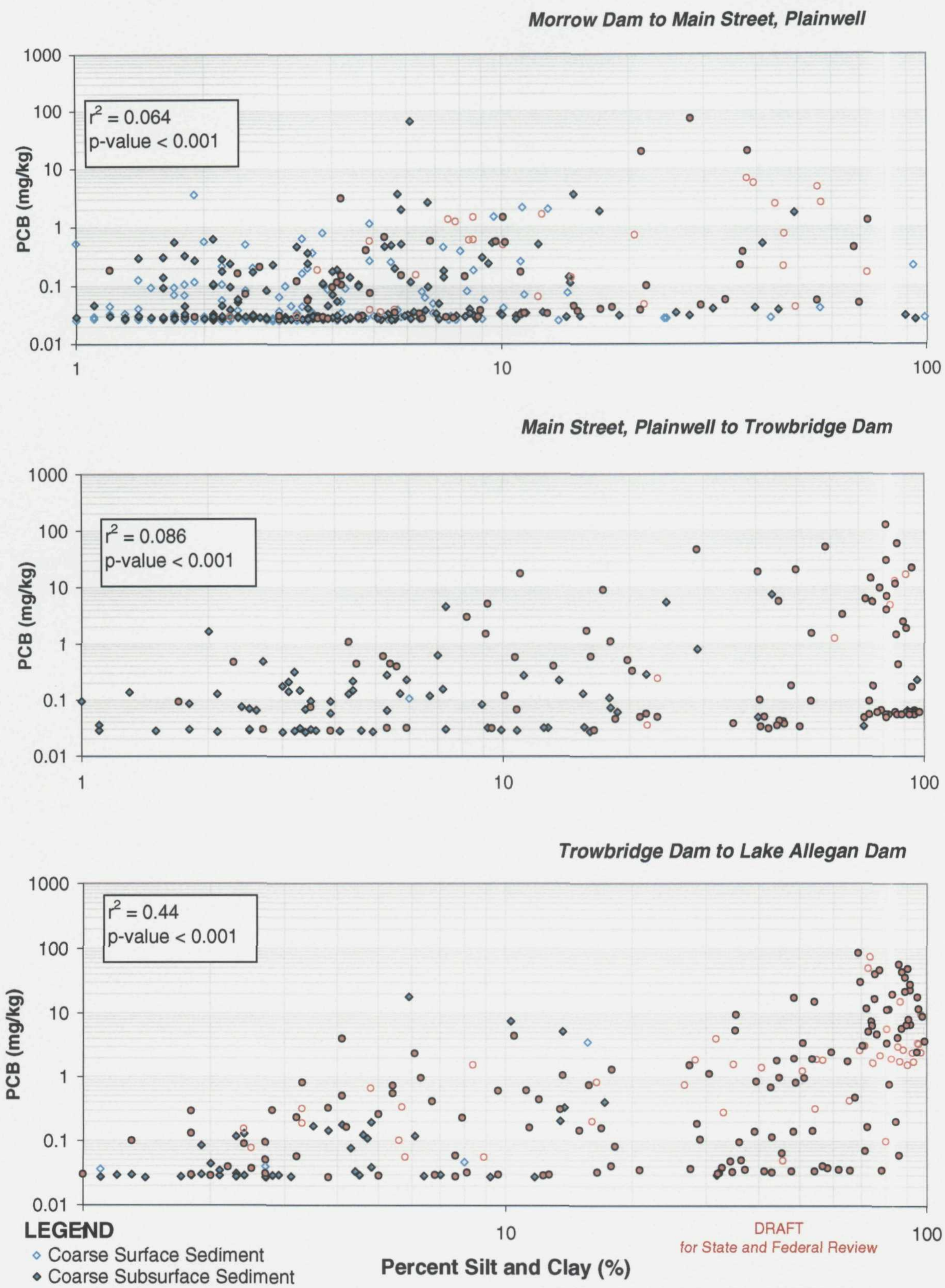
REMEDIAL INVESTIGATION REPORT

FREQUENCY DISTRIBUTION OF SILT & CLAY IN SEDIMENT AND PCB CONCENTRATIONS IN SEDIMENT

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 4-10

MJS_msmulti2.xls_4-10



NOTES:

1. Three samples from Morrow Dam to Main Street, Plainwell and two samples from Trowbridge Dam to Lake Allegan Dam had reported percent silt and clay less than 1%.
2. Regression analyses were performed on log-transformed PCB data.

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ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

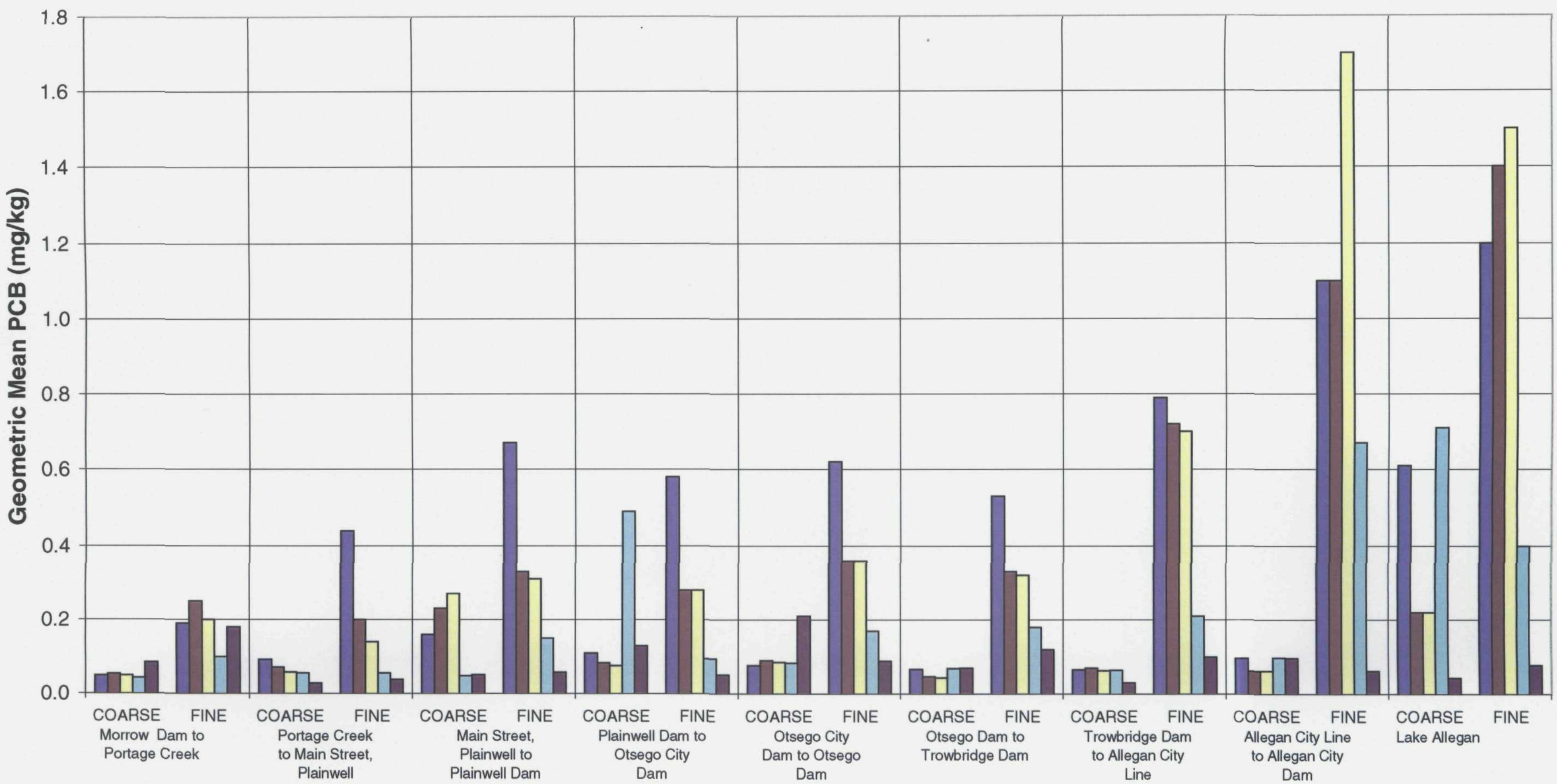
REMEDIAL INVESTIGATION REPORT

RELATIONSHIP OF PCB CONCENTRATION AND PERCENT SILT AND CLAY IN SEDIMENT

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **4-11**

MJS_msmult2.xls_4-11



LEGEND

- 0" - 2" depth interval
- 2" - 6" depth interval
- 6" - 12" depth interval
- 12" - 24" depth interval
- Samples deeper than 24"

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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

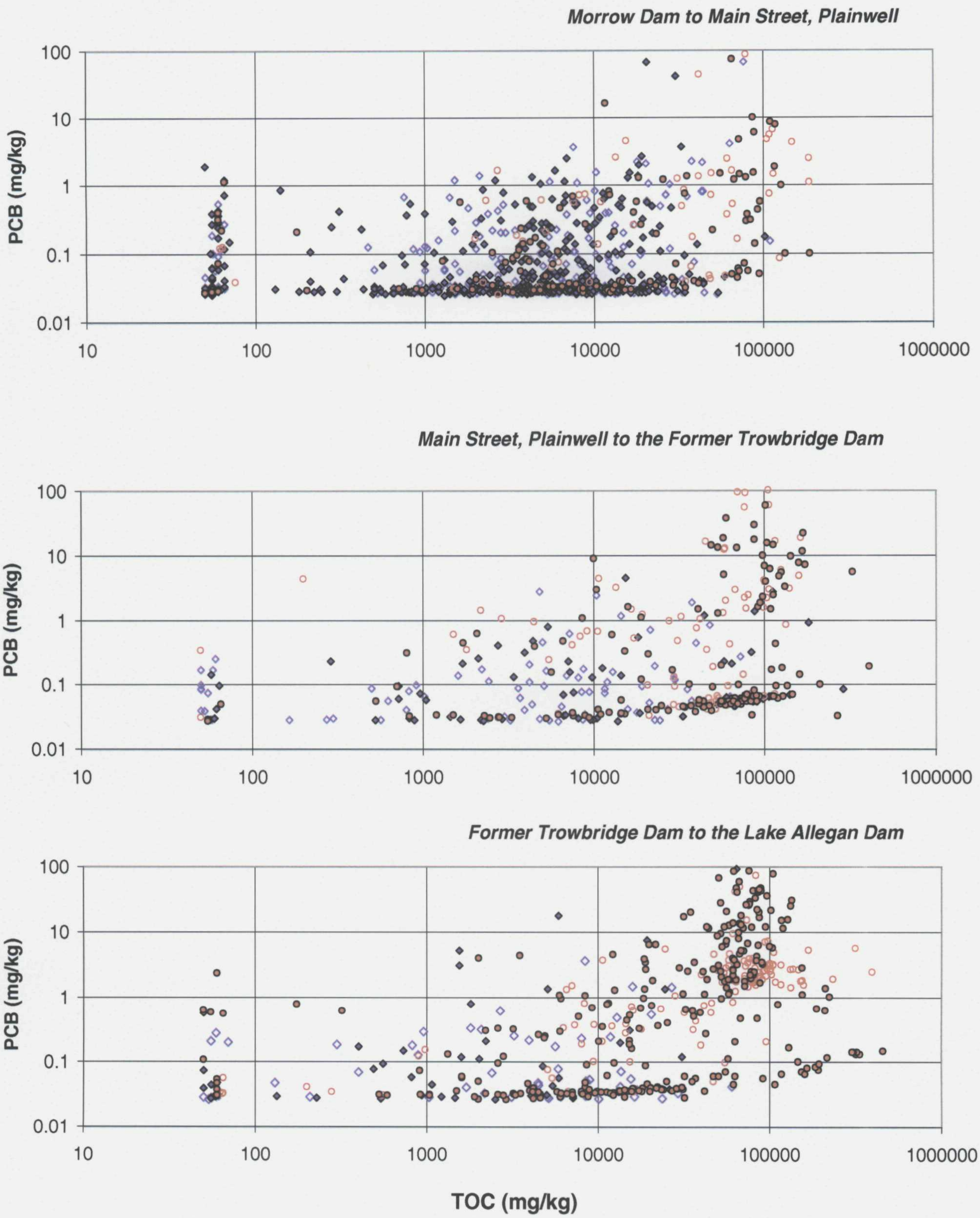
REMEDIAL INVESTIGATION REPORT

GEOMETRIC MEAN PCB CONCENTRATIONS IN SEDIMENT BY TEXTURE AND DEPTH

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 4-12

MJS_kPCBsummary.xls_4-12



LEGEND

- ◇ Coarse Surface Sediment
- ◆ Coarse Subsurface Sediment
- ○ Fine Surface Sediment
- ● Fine Subsurface Sediment

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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

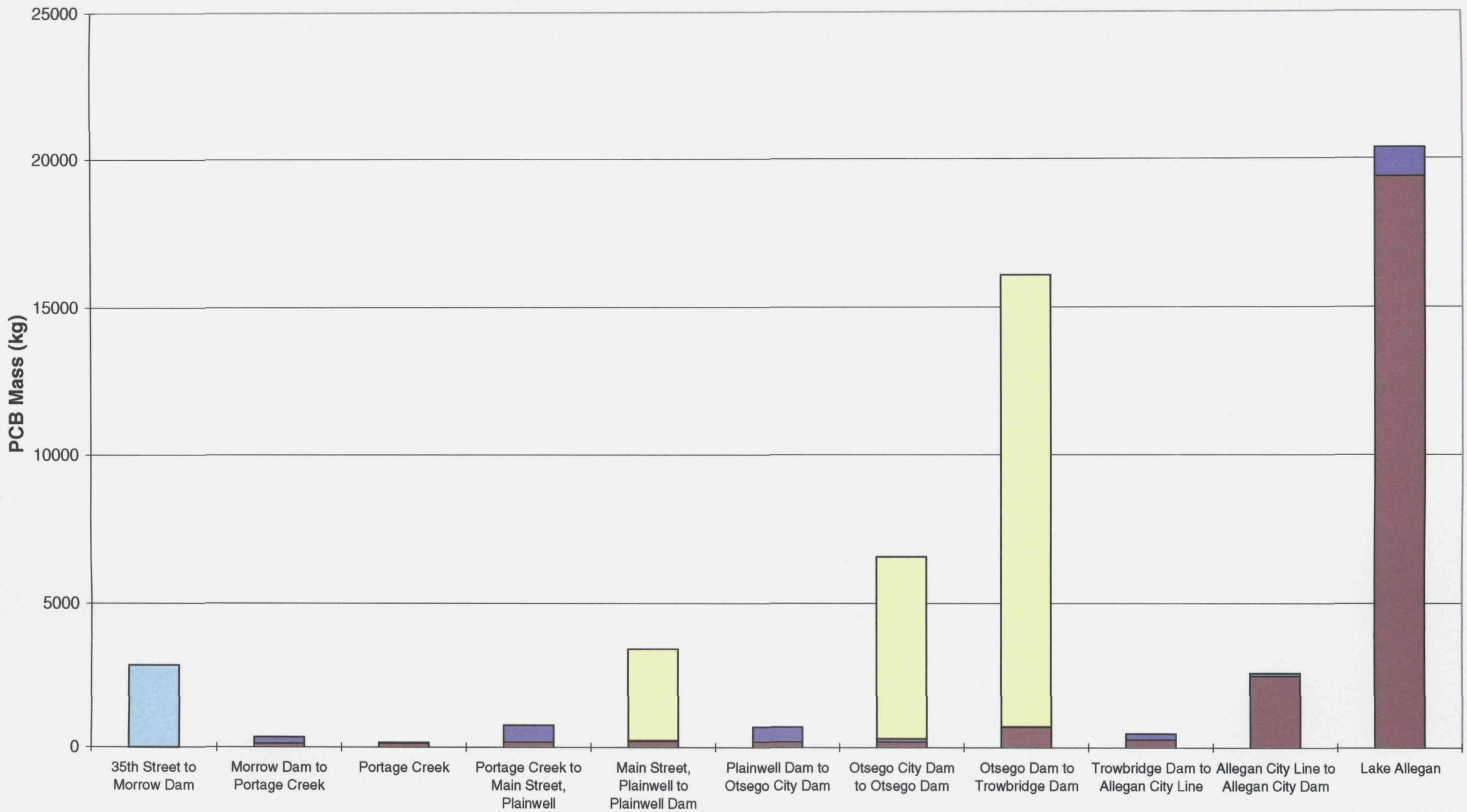
REMEDIAL INVESTIGATION REPORT

RELATIONSHIP OF PCB AND TOC IN THE KALAMAZOO RIVER BY SEDIMENT CLASSIFICATION

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-13

MJS_ktocgraph.xls_4-13



LEGEND

- Morrow Lake Sediment
- Former Impoundment Exposed Sediment
- Coarse Channel Sediment
- Fine Channel Sediment

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ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

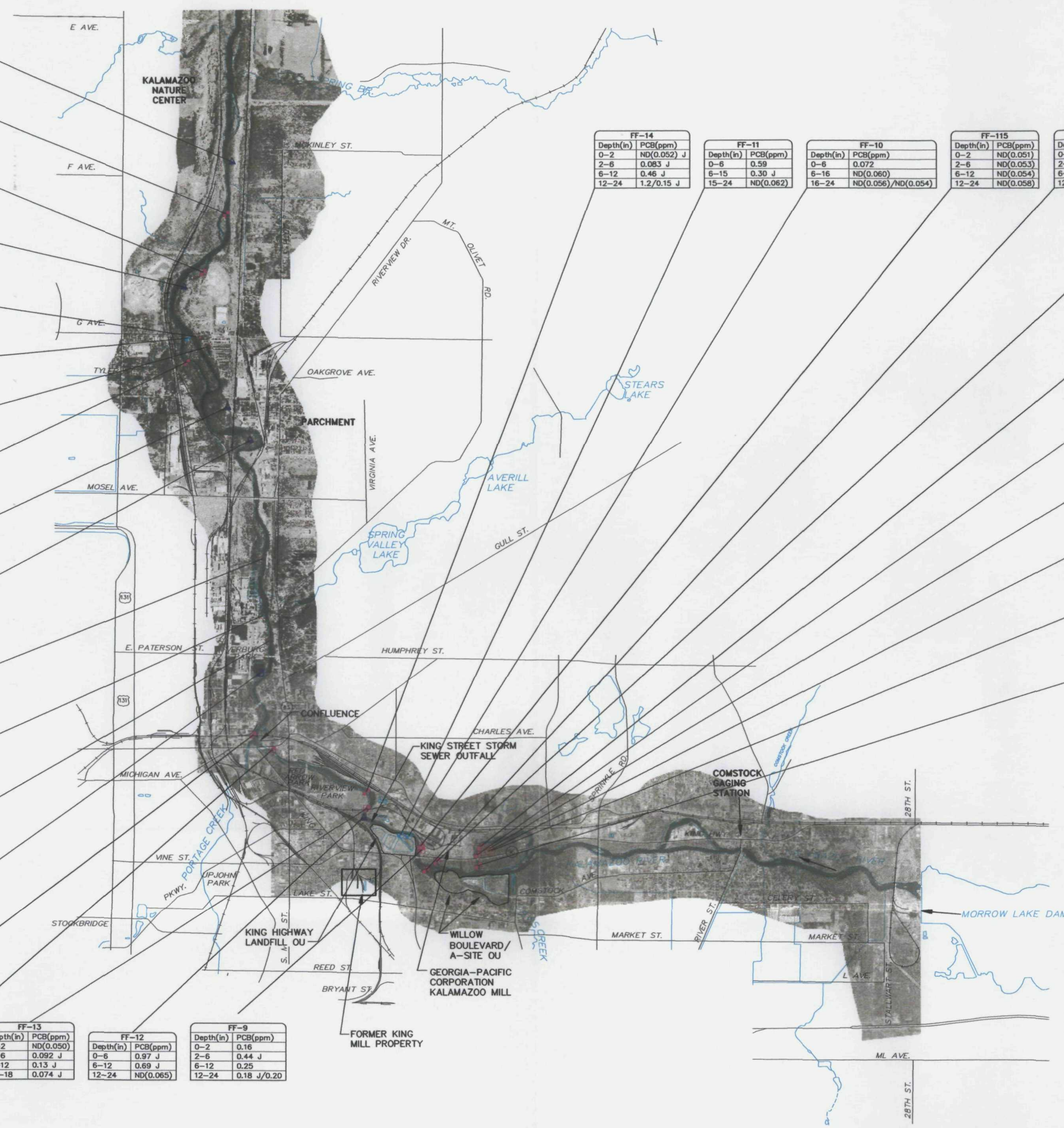
REMEDIAL INVESTIGATION REPORT

ESTIMATED PCB MASS IN KALAMAZOO RIVER AND PORTAGE CREEK SEDIMENT BY TYPE

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-14

MJS_newFINLMASS.xls_4-14



FF-30

Depth(in)	PCB(ppm)
0-6	1.4 J
6-12	0.58 J
12-23	ND(0.074) J

FF-29

Depth(in)	PCB(ppm)
0-2	0.13 J
2-7	ND(0.074)/ND(0.068)

FF-28

Depth(in)	PCB(ppm)
0-2	7.2
2-6	9.5
6-14	14
14-23	66/60

FF-27

Depth(in)	PCB(ppm)
0-6	1.3
6-12	ND(0.10)
12-23	ND(0.080)

FF-25

Depth(in)	PCB(ppm)
0-2	0.072 J
2-6	0.12 J
6-12	0.16 J
12-24	0.58 J/0.46

FF-26

Depth(in)	PCB(ppm)
0-6	ND(0.094) J
6-14	ND(0.088)
14-23	ND(0.069)

FF-24

Depth(in)	PCB(ppm)
0-2	0.39 J
2-6	0.37 J
6-14	0.73

FF-23

Depth(in)	PCB(ppm)
0-2	ND(0.059)
2-6	ND(0.071)
6-18	ND(0.064)

FF-22

Depth(in)	PCB(ppm)
0-6	0.47 J
6-12	0.043 J

FF-21

Depth(in)	PCB(ppm)
0-6	0.56 J
6-12	0.10 J
12-15	ND(0.064)
15-24	ND(0.078)/ND(0.077)

FF-20

Depth(in)	PCB(ppm)
0-2	0.23 J
2-6	0.085 J
6-12	0.044 J
12-24	0.16 J/0.098

FF-19

Depth(in)	PCB(ppm)
0-2	0.18
2-6	0.29
6-10	27
10-24	1.5

FF-18

Depth(in)	PCB(ppm)
0-2	0.60
2-6	5.1
6-12	6.7
12-16	0.63

FF-17

Depth(in)	PCB(ppm)
0-2	0.31
2-6	0.15 J
6-12	0.33
12-24	0.23 J

FF-16

Depth(in)	PCB(ppm)
0-2	0.91
2-6	6.0 J/5.4 J
6-12	18

FF-15

Depth(in)	PCB(ppm)
0-2	1.2 J
2-6	0.80 J
6-12	18
12-24	0.22 J

FF-14

Depth(in)	PCB(ppm)
0-2	ND(0.052) J
2-6	0.083 J
6-12	0.46 J
12-24	1.2/0.15 J

FF-11

Depth(in)	PCB(ppm)
0-6	0.59
6-15	0.30 J
15-24	ND(0.062)

FF-10

Depth(in)	PCB(ppm)
0-6	0.072
6-16	ND(0.060)
16-24	ND(0.056)/ND(0.054)

FF-115

Depth(in)	PCB(ppm)
0-2	ND(0.051)
2-6	ND(0.053)
6-12	ND(0.054)
12-24	ND(0.058)

FF-8

Depth(in)	PCB(ppm)
0-2	ND(0.062)
2-6	0.036 J
6-12	ND(0.056)
12-24	0.084 J/0.084 J

FF-7

Depth(in)	PCB(ppm)
0-2	1.2
2-6	1.2 J
6-12	ND(0.12)
12-24	ND(0.12)/ND(0.11)

FF-4

Depth(in)	PCB(ppm)
0-2	0.57 J
2-6	0.092
6-12	ND(0.054)
12-22	0.031 J

FF-5

Depth(in)	PCB(ppm)
0-2	0.56 J
2-6	0.79 J
6-12	2.4 J
12-24	0.87/0.69 J

FF-2

Depth(in)	PCB(ppm)
0-8	0.27 J
8-12	ND(0.085)
12-22	ND(0.075)/ND(0.076)

FF-3

Depth(in)	PCB(ppm)
0-6	0.15 J
6-12	220
12-24	ND(0.065)

FF-1

Depth(in)	PCB(ppm)
0-6	0.93
6-14	ND(0.15)
14-18	ND(0.070)
18-24	ND(0.063)/ND(0.063)

FF-6

Depth(in)	PCB(ppm)
0-2	ND(0.055)
2-6	ND(0.052)
6-12	ND(0.054)
12-20	ND(0.062)

FF-13

Depth(in)	PCB(ppm)
0-2	ND(0.050)
2-6	0.092 J
6-12	0.13 J
12-18	0.074 J

FF-12

Depth(in)	PCB(ppm)
0-6	0.97 J
6-12	0.69 J
12-24	ND(0.065)

FF-9

Depth(in)	PCB(ppm)
0-2	0.16
2-6	0.44 J
6-12	0.25
12-24	0.18 J/0.20

LEGEND

SAMPLE LOCATION TYPE:

- KALAMAZOO RIVER SEDIMENT
- FLOODPLAIN SOIL
- FORMER IMPOUNDMENT EXPOSED SEDIMENT
- KALAMAZOO RIVER ISLAND
- OTSEGO CITY IMPOUNDMENT
- POINT SOURCE AND WASTE DISPOSAL

NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2000' 4000'
GRAPHIC SCALE

DRAFT
FOR STATE AND FEDERAL REVIEW

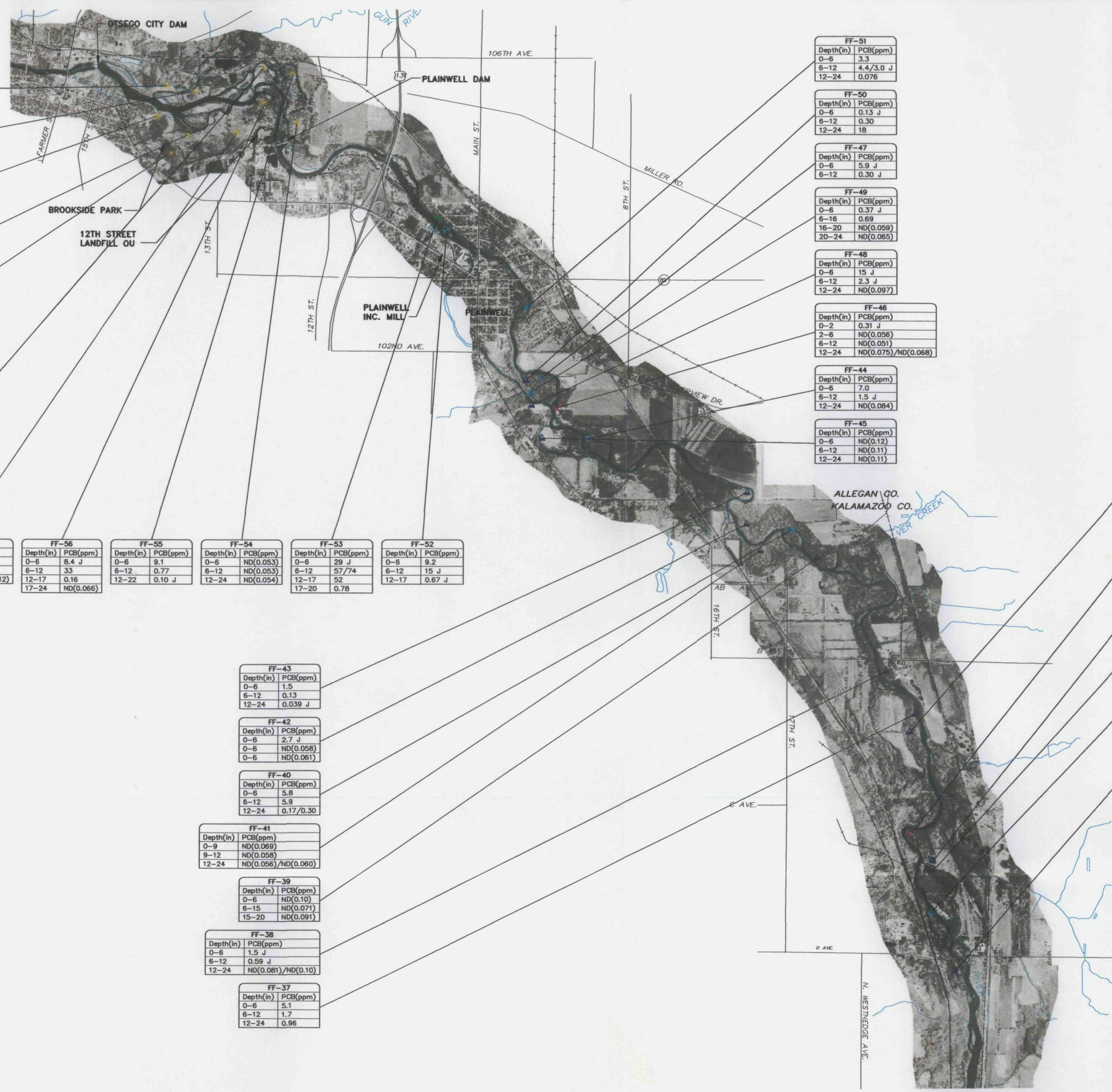
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE
REMEDIAL INVESTIGATION REPORT

FOCUSED SAMPLING LOCATIONS - MORROW DAM TO E-AVENUE

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **4-15**

X: 64524X01.TIF, 64524X02.TIF
L: ON=*, OFF=*REF*, SP-DATA
P: STD-PCP/DL.PCP
10/26/00 SYR-54-GMS JER KMD
64524500/BOARDS/64524C07.DWG



FF-62

Depth(in)	PCB(ppm)
0-6	0.11 J
6-12	0.087 J
12-24	0.59

FF-59

Depth(in)	PCB(ppm)
0-8	0.21
8-12	ND(0.058)
12-24	ND(0.058)/ND(0.062)

FF-63

Depth(in)	PCB(ppm)
0-6	ND(0.24)
6-12	ND(0.35)
12-19	ND(0.38)/ND(0.36)
19-24	ND(0.16)

FF-60

Depth(in)	PCB(ppm)
0-6	4.1 J
6-12	0.19 J
12-19	ND(0.18)
19-24	ND(0.065)

FF-61

Depth(in)	PCB(ppm)
0-6	ND(0.30)
6-12	ND(0.31)
12-24	ND(0.33)/ND(0.33)

FF-51

Depth(in)	PCB(ppm)
0-6	3.3
6-12	4.4/3.0 J
12-24	0.076

FF-50

Depth(in)	PCB(ppm)
0-6	0.13 J
6-12	0.30
12-24	18

FF-47

Depth(in)	PCB(ppm)
0-6	5.9 J
6-12	0.30 J

FF-49

Depth(in)	PCB(ppm)
0-6	0.37 J
6-16	0.69
16-20	ND(0.059)
20-24	ND(0.065)

FF-48

Depth(in)	PCB(ppm)
0-6	15 J
6-12	2.3 J
12-24	ND(0.097)

FF-46

Depth(in)	PCB(ppm)
0-2	0.31 J
2-6	ND(0.056)
6-12	ND(0.051)
12-24	ND(0.075)/ND(0.068)

FF-44

Depth(in)	PCB(ppm)
0-6	7.0
6-12	1.5 J
12-24	ND(0.084)

FF-45

Depth(in)	PCB(ppm)
0-6	ND(0.12)
6-12	ND(0.11)
12-24	ND(0.11)

FF-36

Depth(in)	PCB(ppm)
0-6	1.4
6-12	0.40 J
12-24	0.096 J

FF-35

Depth(in)	PCB(ppm)
0-2	3.1 J
2-6	8.2 J
6-15	0.13 J

FF-34

Depth(in)	PCB(ppm)
0-2	ND(0.078)
2-6	ND(0.082)
6-12	ND(0.061)
12-19	ND(0.057)

FF-33

Depth(in)	PCB(ppm)
0-2	0.13 J
2-6	0.13 J
6-12	ND(0.15)
12-24	ND(0.085)

FF-32

Depth(in)	PCB(ppm)
0-6	2.2
6-12	1.3
12-24	0.13 J

FF-31

Depth(in)	PCB(ppm)
0-6	0.21 J
6-12	0.047 J
12-24	ND(0.071)/ND(0.074)

FF-57

Depth(in)	PCB(ppm)
0-6	7.7
6-12	2.2
12-18	ND(0.10)
18-25	ND(0.070)

FF-58

Depth(in)	PCB(ppm)
0-6	ND(0.062)
6-13	ND(0.075)
13-23	ND(0.22)/ND(0.12)

FF-56

Depth(in)	PCB(ppm)
0-6	8.4 J
6-12	33
12-17	0.16
17-24	ND(0.066)

FF-55

Depth(in)	PCB(ppm)
0-6	9.1
6-12	0.77
12-22	0.10 J

FF-54

Depth(in)	PCB(ppm)
0-6	ND(0.053)
6-12	ND(0.053)
12-24	ND(0.054)

FF-53

Depth(in)	PCB(ppm)
0-6	29 J
6-12	57/74
12-17	52
17-20	0.78

FF-52

Depth(in)	PCB(ppm)
0-6	9.2
6-12	15 J
12-17	0.67 J

FF-43

Depth(in)	PCB(ppm)
0-6	1.5
6-12	0.13
12-24	0.039 J

FF-42

Depth(in)	PCB(ppm)
0-6	2.7 J
0-6	ND(0.058)
0-6	ND(0.061)

FF-40

Depth(in)	PCB(ppm)
0-6	5.8
6-12	5.9
12-24	0.17/0.30

FF-41

Depth(in)	PCB(ppm)
0-9	ND(0.069)
9-12	ND(0.058)
12-24	ND(0.056)/ND(0.060)

FF-39

Depth(in)	PCB(ppm)
0-6	ND(0.10)
6-15	ND(0.071)
15-20	ND(0.091)

FF-38

Depth(in)	PCB(ppm)
0-6	1.5 J
6-12	0.59 J
12-24	ND(0.081)/ND(0.10)

FF-37

Depth(in)	PCB(ppm)
0-6	5.1
6-12	1.7
12-24	0.96

LEGEND

SAMPLE LOCATION TYPE:

- KALAMAZOO RIVER SEDIMENT
- FLOODPLAIN SOIL
- FORMER IMPOUNDMENT EXPOSED SEDIMENT
- KALAMAZOO RIVER ISLAND
- OTSEGO CITY IMPOUNDMENT
- POINT SOURCE AND WASTE DISPOSAL

NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

0 2000' 4000'
GRAPHIC SCALE

DRAFT
FOR STATE AND FEDERAL REVIEW

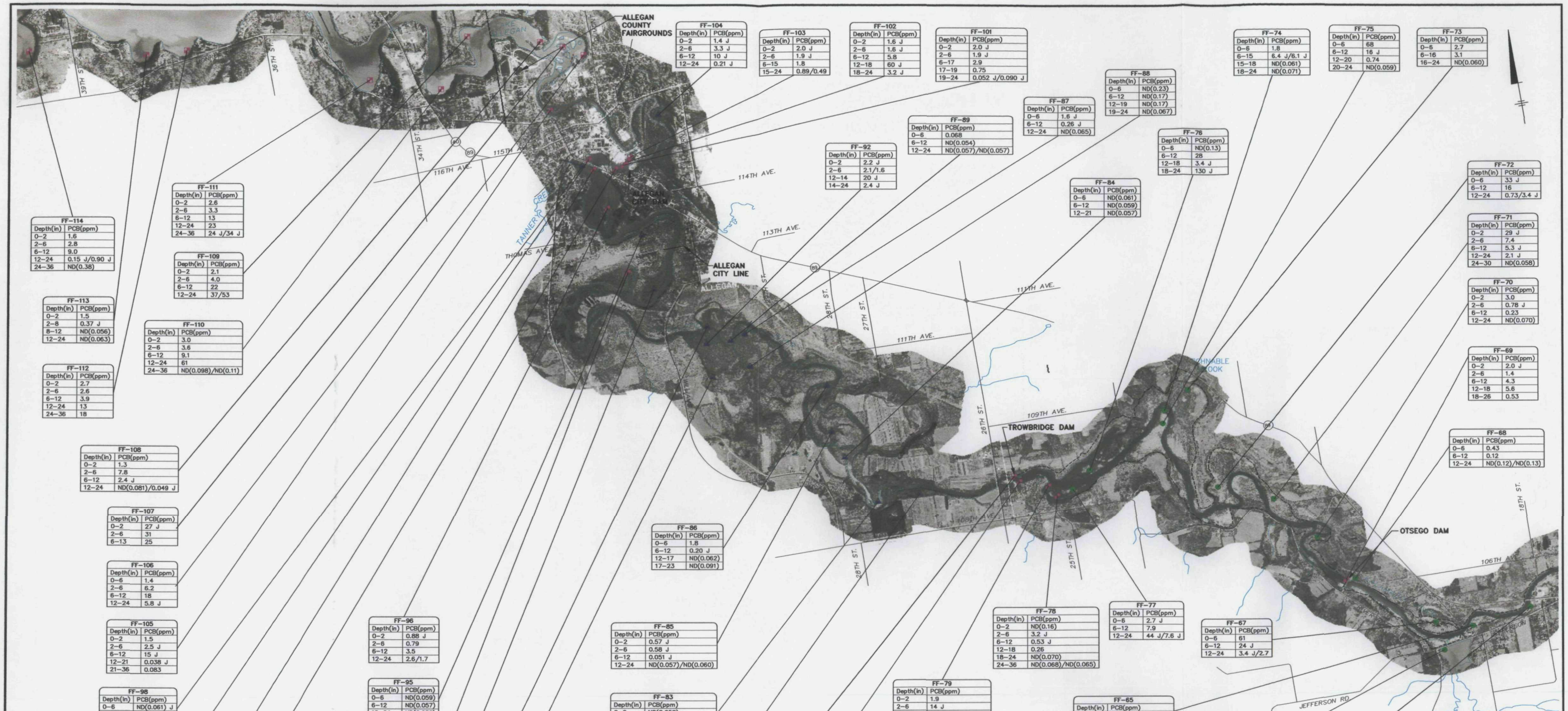
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE
REMEDIAL INVESTIGATION REPORT

FOCUSED SAMPLING LOCATIONS - D-AVENUE TO THE OTSEGO CITY DAM

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **4-16**

X: 64524X03.TIF, 64524X04.TIF
L: ON=*, OFF=*REF*, SP-LABEL
P: STD-PCP/DL.PCP
10/26/00 SYR-54-GMS JER KMD
64524500/BOARDS/64524C08.DWG



FF-114

Depth(in)	PCB(ppm)
0–2	1.6
2–6	2.8
6–12	9.0
12–24	0.15 J/0.90 J
24–36	ND(0.38)

FF-113

Depth(in)	PCB(ppm)
0–2	1.5
2–8	0.37 J
8–12	ND(0.056)
12–24	ND(0.063)

FF-112

Depth(in)	PCB(ppm)
0–2	2.7
2–6	2.6
6–12	3.9
12–24	13
24–36	18

FF-111

Depth(in)	PCB(ppm)
0–2	2.6
2–6	3.3
6–12	13
12–24	23
24–36	24 J/34 J

FF-109

Depth(in)	PCB(ppm)
0–2	2.1
2–6	4.0
6–12	22
12–24	37/53

FF-110

Depth(in)	PCB(ppm)
0–2	3.0
2–6	3.6
6–12	9.1
12–24	61
24–36	ND(0.098)/ND(0.11)

FF-108

Depth(in)	PCB(ppm)
0–2	1.3
2–6	7.8
6–12	2.4 J
12–24	ND(0.081)/0.049 J

FF-107

Depth(in)	PCB(ppm)
0–2	27 J
2–6	31
6–13	25

FF-106

Depth(in)	PCB(ppm)
0–6	1.4
2–6	6.2
6–12	18
12–24	5.8 J

FF-105

Depth(in)	PCB(ppm)
0–2	1.5
2–6	2.5 J
6–12	15 J
12–21	0.038 J
21–36	0.083

FF-98

Depth(in)	PCB(ppm)
0–6	ND(0.061) J
6–12	ND(0.075) J
12–24	2.5 J

FF-99

Depth(in)	PCB(ppm)
0–2	3.5
2–6	4.3
6–12	54 J
12–24	4.4

FF-97

Depth(in)	PCB(ppm)
0–2	2.4
2–6	2.3
6–12	2.7
12–18	0.23 J
18–24	0.36
24–33	ND(0.072)/ND(0.071)

FF-100

Depth(in)	PCB(ppm)
0–2	2.5
2–6	2.5 J
6–12	10
12–24	42 J

FF-104

Depth(in)	PCB(ppm)
0–2	1.4 J
2–6	3.3 J
6–12	10 J
12–24	0.21 J

FF-103

Depth(in)	PCB(ppm)
0–2	2.0 J
2–6	1.9 J
6–15	1.8
15–24	0.89/0.49

FF-102

Depth(in)	PCB(ppm)
0–2	1.6 J
2–6	1.6 J
6–12	5.8
12–18	60 J
18–24	3.2 J

FF-101

Depth(in)	PCB(ppm)
0–2	2.0 J
2–6	1.9 J
6–17	2.9
17–19	0.75
19–24	0.052 J/0.090 J

FF-92

Depth(in)	PCB(ppm)
0–2	2.2 J
2–6	2.1/1.6
12–14	20 J
14–24	2.4 J

FF-89

Depth(in)	PCB(ppm)
0–6	0.068
6–12	ND(0.054)
12–24	ND(0.057)/ND(0.057)

FF-87

Depth(in)	PCB(ppm)
0–6	1.6 J
6–12	0.26 J
12–24	ND(0.065)

FF-88

Depth(in)	PCB(ppm)
0–6	ND(0.23)
6–12	ND(0.17)
12–19	ND(0.17)
19–24	ND(0.067)

FF-84

Depth(in)	PCB(ppm)
0–6	ND(0.061)
6–12	ND(0.059)
12–21	ND(0.057)

FF-76

Depth(in)	PCB(ppm)
0–6	ND(0.13)
6–12	28
12–18	3.4 J
18–24	130 J

FF-74

Depth(in)	PCB(ppm)
0–6	1.8
6–15	6.4 J/6.1 J
15–18	ND(0.061)
18–24	ND(0.071)

FF-75

Depth(in)	PCB(ppm)
0–6	68
6–12	16 J
12–20	0.74
20–24	ND(0.059)

FF-73

Depth(in)	PCB(ppm)
0–6	2.7
6–16	3.1
16–24	ND(0.060)

FF-72

Depth(in)	PCB(ppm)
0–6	33 J
6–12	16
12–24	0.73/3.4 J

FF-71

Depth(in)	PCB(ppm)
0–2	29 J
2–6	7.4
6–12	5.3 J
12–24	2.1 J
24–30	ND(0.058)

FF-70

Depth(in)	PCB(ppm)
0–2	3.0
2–6	0.78 J
6–12	0.23
12–24	ND(0.070)

FF-69

Depth(in)	PCB(ppm)
0–2	2.0 J
2–6	1.4
6–12	4.3
12–18	5.6
18–26	0.53

FF-68

Depth(in)	PCB(ppm)
0–6	0.43
6–12	0.12
12–24	ND(0.12)/ND(0.13)

FF-86

Depth(in)	PCB(ppm)
0–6	1.8
6–12	0.20 J
12–17	ND(0.062)
17–23	ND(0.091)

FF-96

Depth(in)	PCB(ppm)
0–2	0.88 J
2–6	0.79
6–12	3.5
12–24	2.6/1.7

FF-95

Depth(in)	PCB(ppm)
0–6	ND(0.059)
6–12	ND(0.057)
12–24	ND(0.058)

FF-93

Depth(in)	PCB(ppm)
0–2	2.4 J
2–6	2.7
6–12	13
12–24	42 J/33 J

FF-94

Depth(in)	PCB(ppm)
0–6	2.2
6–12	6.1 J
12–20	ND(0.087)
20–24	ND(0.073)

FF-90

Depth(in)	PCB(ppm)
0–6	0.033 J
6–12	ND(0.058)
12–24	ND(0.057)/ND(0.055)

FF-91

Depth(in)	PCB(ppm)
0–6	ND(0.31)
6–12	ND(0.26)
12–14	ND(0.085)
14–24	ND(0.065)

FF-85

Depth(in)	PCB(ppm)
0–2	0.57 J
2–6	0.58 J
6–12	0.051 J
12–24	ND(0.057)/ND(0.060)

FF-83

Depth(in)	PCB(ppm)
0–2	ND(0.058)
2–6	ND(0.054)
6–12	ND(0.053)
12–24	ND(0.055)/ND(0.053)

FF-82

Depth(in)	PCB(ppm)
0–6	ND(0.082)
6–12	ND(0.085)
12–20	ND(0.10)
20–26	ND(0.060)/ND(0.059)

FF-81

Depth(in)	PCB(ppm)
0–2	3.6
2–6	13
6–12	76 J
12–26	0.092/0.27 J

FF-80

Depth(in)	PCB(ppm)
0–2	0.54
2–6	0.68
6–12	1.9 J
12–24	16
24–36	120 J

FF-78

Depth(in)	PCB(ppm)
0–2	ND(0.16)
2–6	3.2 J
6–12	0.53 J
12–18	0.26
18–24	ND(0.070)
24–36	ND(0.068)/ND(0.065)

FF-77

Depth(in)	PCB(ppm)
0–6	2.7 J
6–12	7.9
12–24	44 J/7.6 J

FF-67

Depth(in)	PCB(ppm)
0–6	61
6–12	24 J
12–24	3.4 J/2.7

FF-79

Depth(in)	PCB(ppm)
0–2	1.9
2–6	14 J
6–12	3.6 J
12–22	0.65
22–37	0.046 J/ND(0.063)

FF-65

Depth(in)	PCB(ppm)
0–6	5.7 J
6–12	5.3 J
12–24	ND(0.096)/ND(0.10)

FF-64

Depth(in)	PCB(ppm)
0–6	11
6–12	12 J
12–24	ND(0.063)

FF-66

Depth(in)	PCB(ppm)
0–2	ND(0.14)
2–6	0.074 J
6–12	16 J
12–24	0.37
24–30	ND(0.072)
30–34	ND(0.064)

LEGEND

SAMPLE LOCATION TYPE:

- KALAMAZOO RIVER SEDIMENT
- FLOODPLAIN SOIL
- FORMER IMPOUNDMENT EXPOSED SEDIMENT
- KALAMAZOO RIVER ISLAND
- OTSEGO CITY IMPOUNDMENT
- POINT SOURCE AND WASTE DISPOSAL

0 2000' 4000'
GRAPHIC SCALE

NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.
2. AERIAL IMAGE DERIVED FROM ORTHOPHOTOGRAPHIC DATA BY AIR LAND SURVEYS, INC., FLOWN 4/24/99.

X: 64524X05.TIF, 64524X06.TIF, 64524X10.TIF
L: ON=*, OFF=*REF*, SP-LABEL
P: STD-PCP/DL.PCP
10/25/00 SYR-54-GMS JER
64524500/BOARDS/64524C09.DWG

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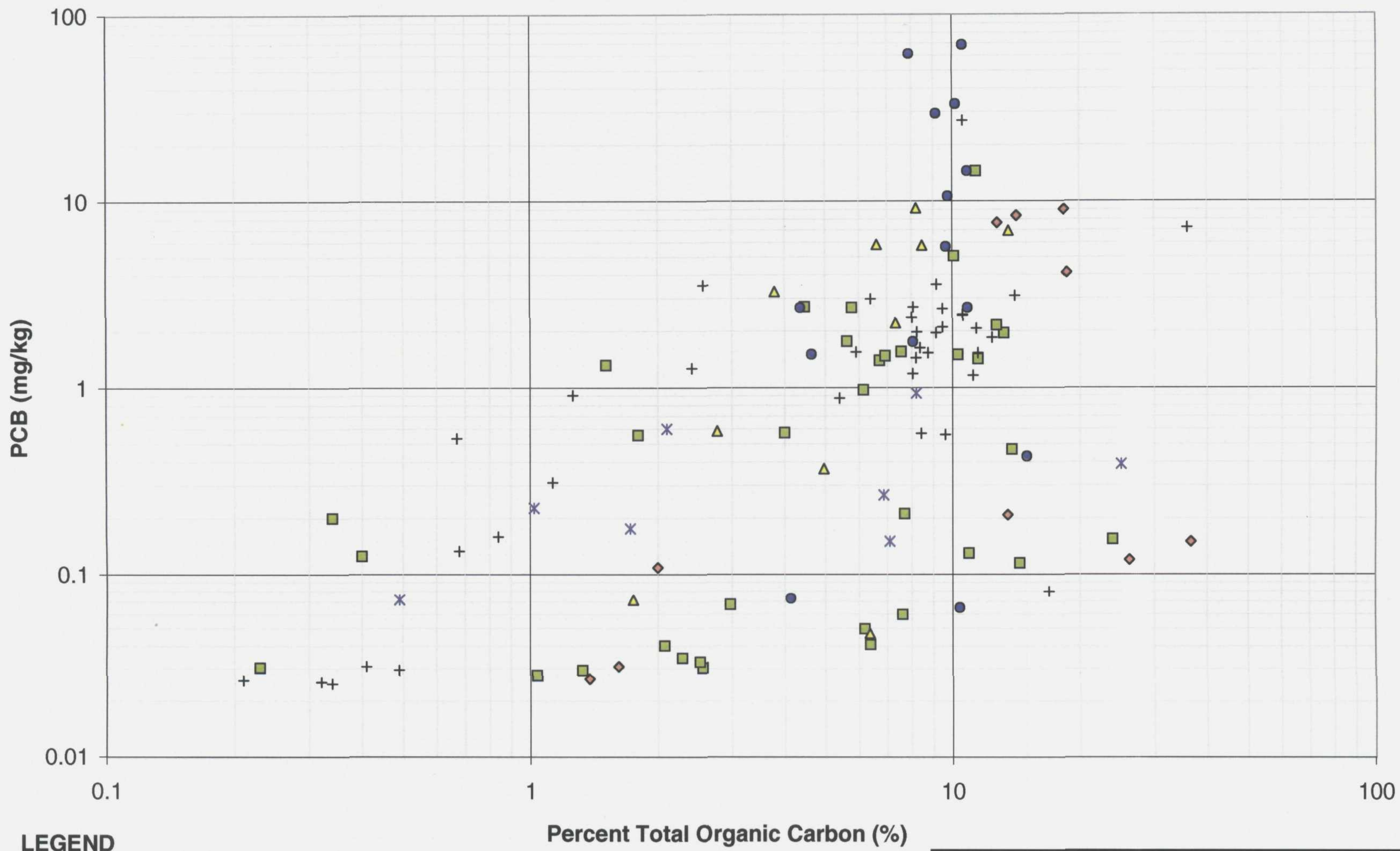
KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE
REMEDIAL INVESTIGATION REPORT

FOCUSED SAMPLING LOCATIONS - 18TH STREET TO LAKE ALLEGAN

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-17



LEGEND

- ■ Floodplain
- ● Exposed Sediment
- ◆ Otsego City Impoundment
- ▲ Kalamazoo River Island
- ✳ Known or Suspected Point Source or Waste Disposal
- \+ Kalamazoo River Sediment

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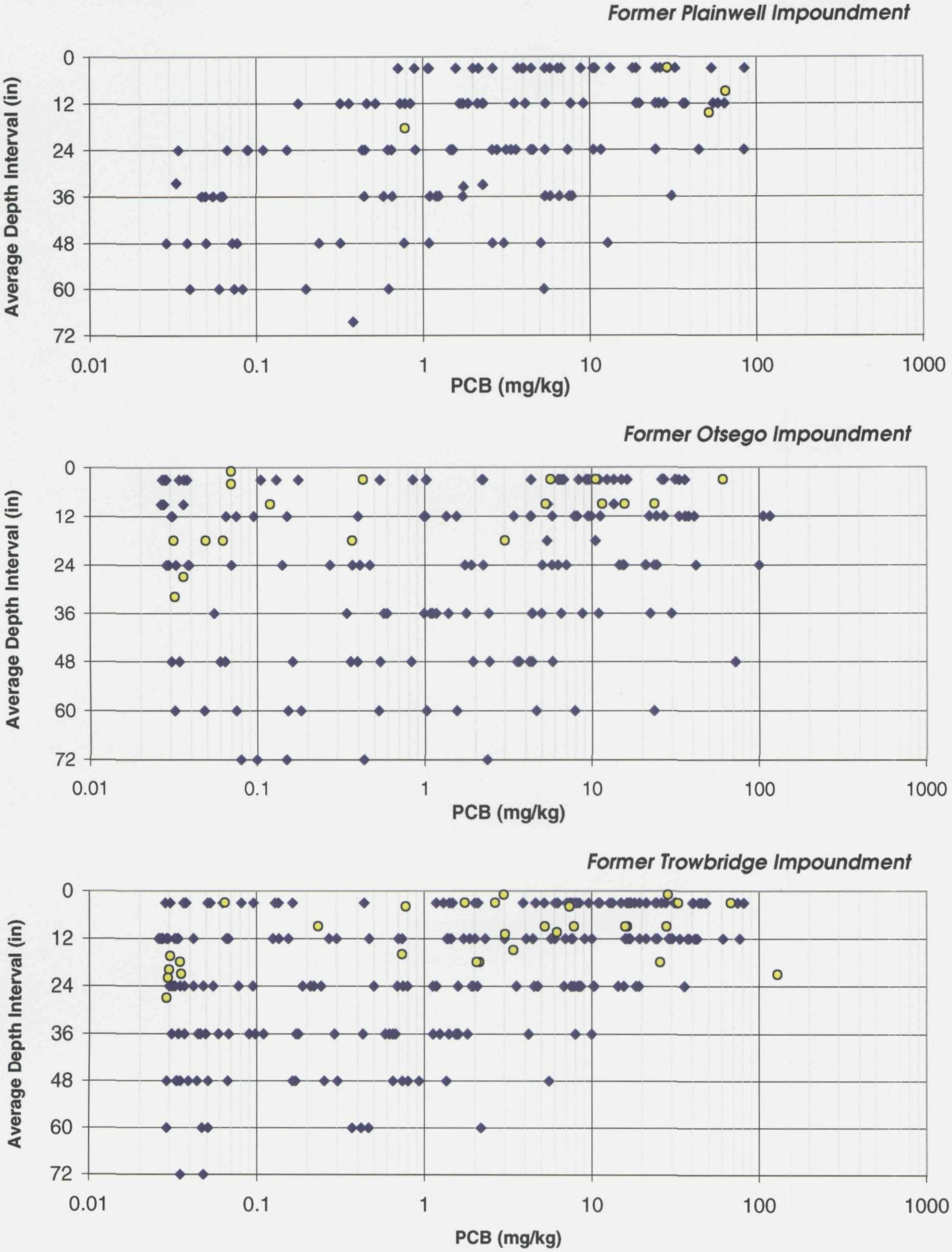
REMEDIAL INVESTIGATION REPORT

PCB CONCENTRATION AND PERCENT TOC IN FOCUSED SAMPLING SURFICIAL SAMPLES BY CLASSIFICATION

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-18

DMP_NEW 4-2.xls_4-18



LEGEND

- ◆ 1994 Former Impoundment Exposed Sediment
- ○ 2000 Focused Former Impoundment Exposed Sediment

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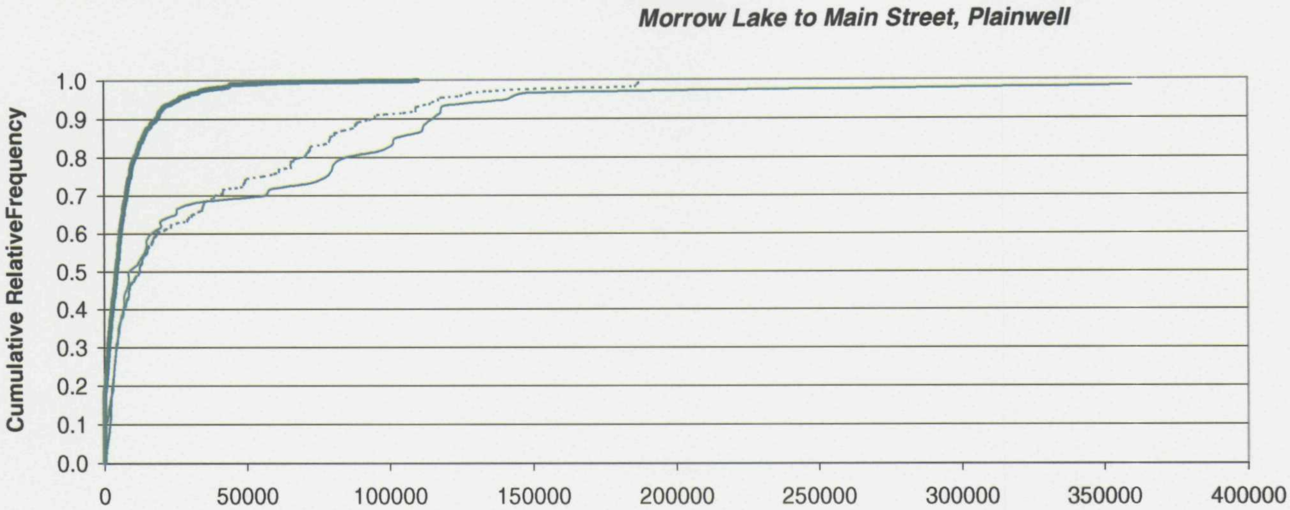
REMEDIAL INVESTIGATION REPORT

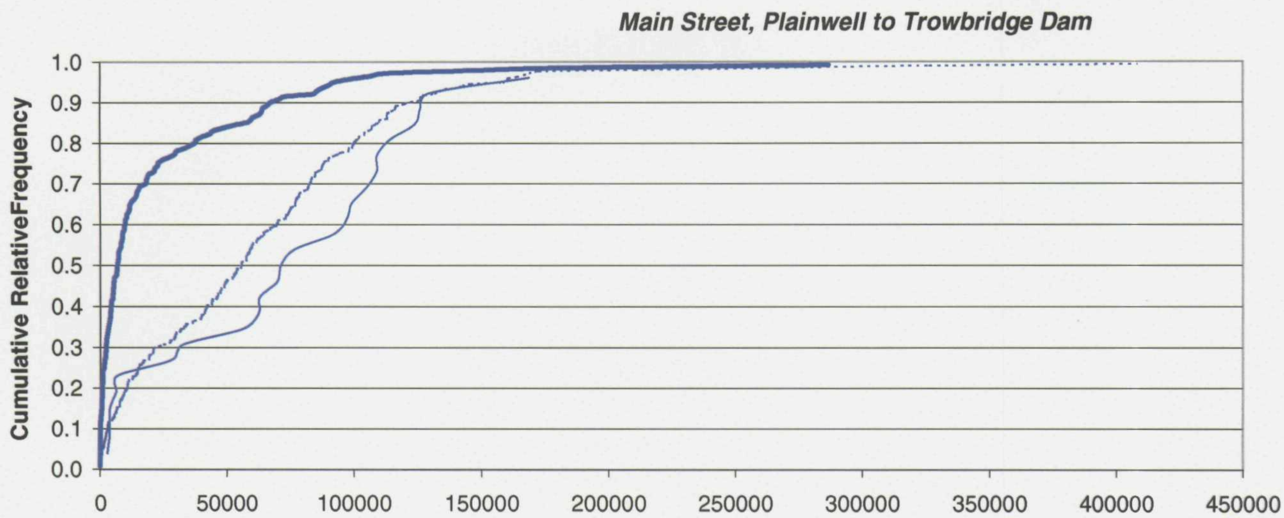
RELATIONSHIP OF PCB CONCENTRATION AND SAMPLE DEPTH - FORMER IMPOUNDMENT AND FOCUSED EXPOSED SEDIMENT SAMPLES

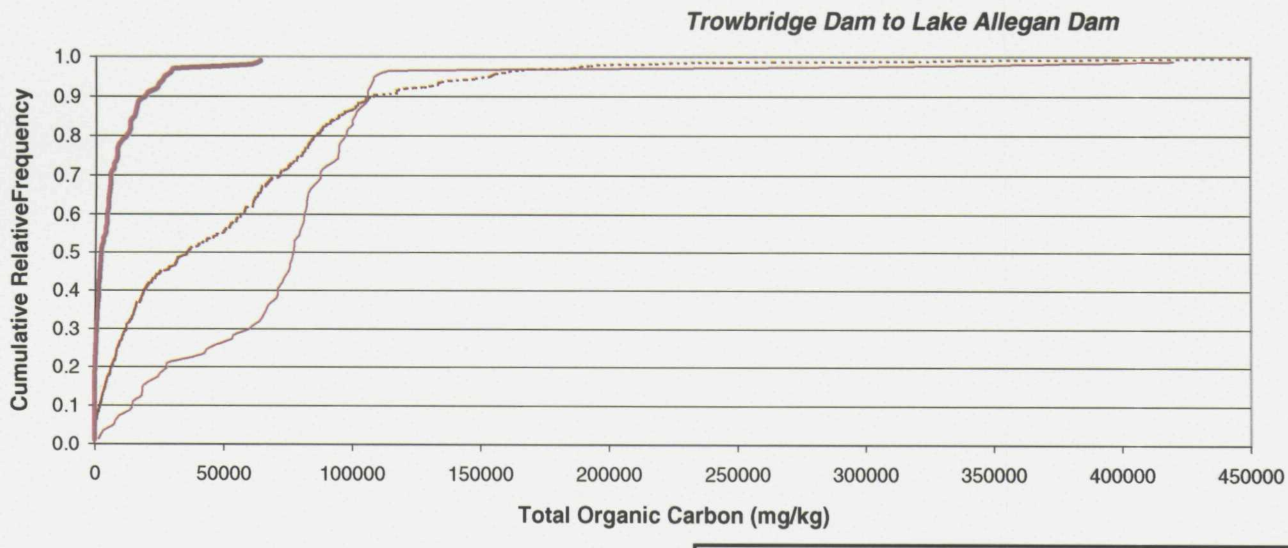
BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-19

DMP_NEW 4-2.xls_4-19







LEGEND

- 2000 Focused Channel Sediment
- 1993 Frozen Core Fine Sediment
- 1993 Frozen Core Coarse Sediment

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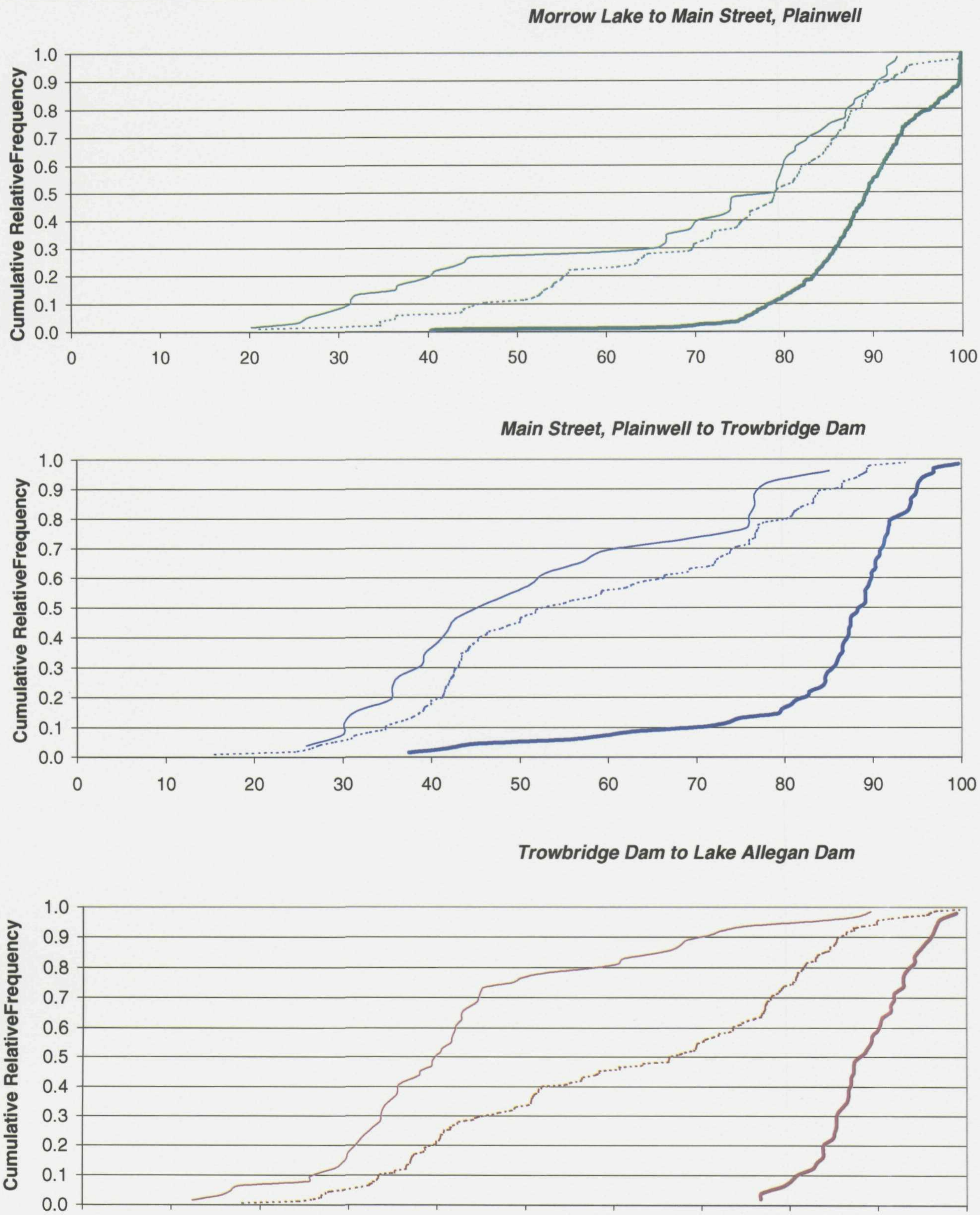
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

FREQUENCY DISTRIBUTION OF TOC IN 1993 FROZEN CORE AND FOCUSED CHANNEL SEDIMENT SAMPLES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-20



LEGEND

- 2000 Focused Channel Sediment
- 1993 Frozen Core Fine Sediment
- 1993 Frozen Core Coarse Sediment

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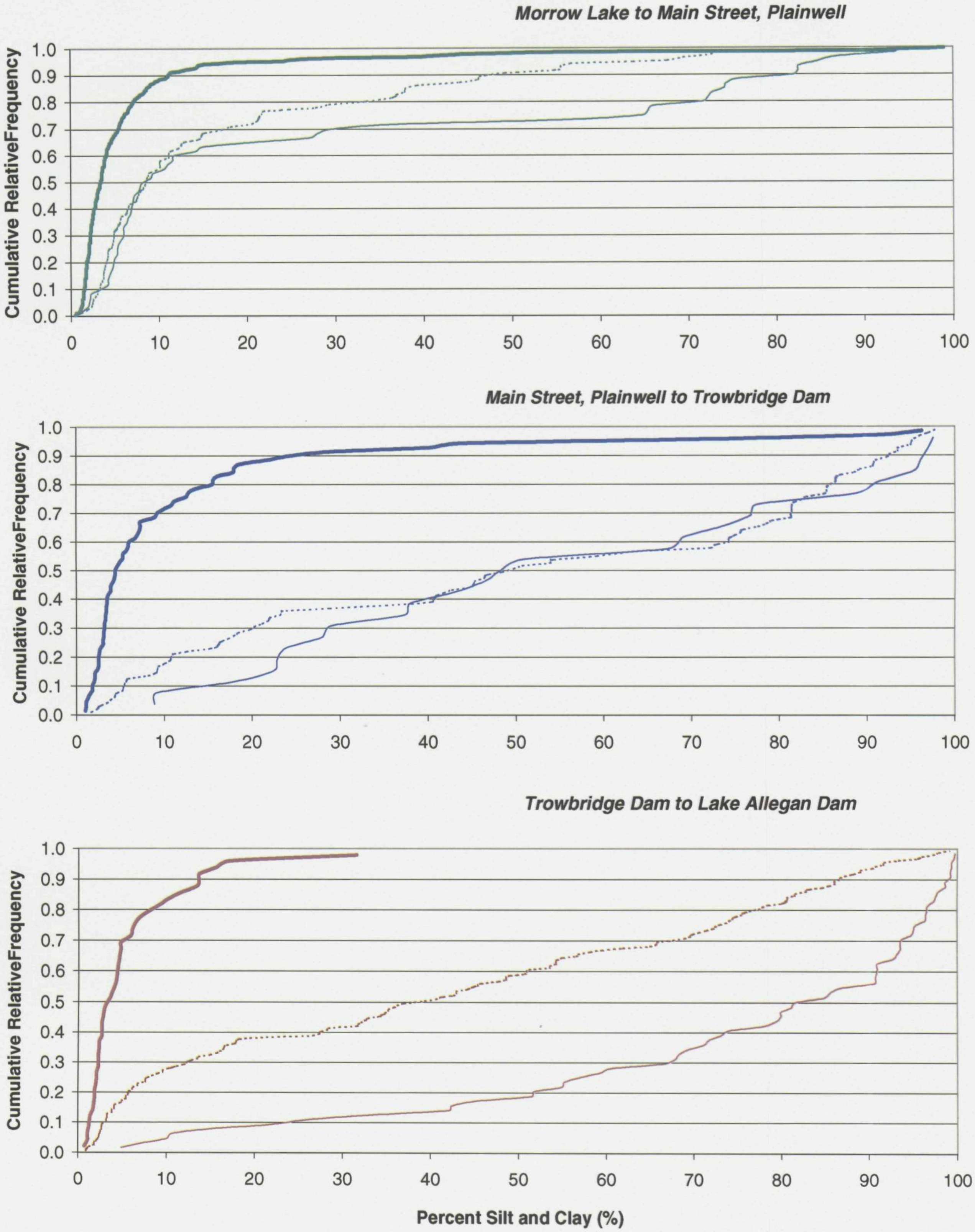
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

REMEDIAL INVESTIGATION REPORT

FREQUENCY DISTRIBUTION OF SOLIDS IN 1993 FROZEN CORE AND FOCUSED CHANNEL SEDIMENT SAMPLES

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 4-21



LEGEND

- 2000 Focused Channel Sediment
- 1993 Frozen Core Fine Sediment
- 1993 Frozen Core Coarse Sediment

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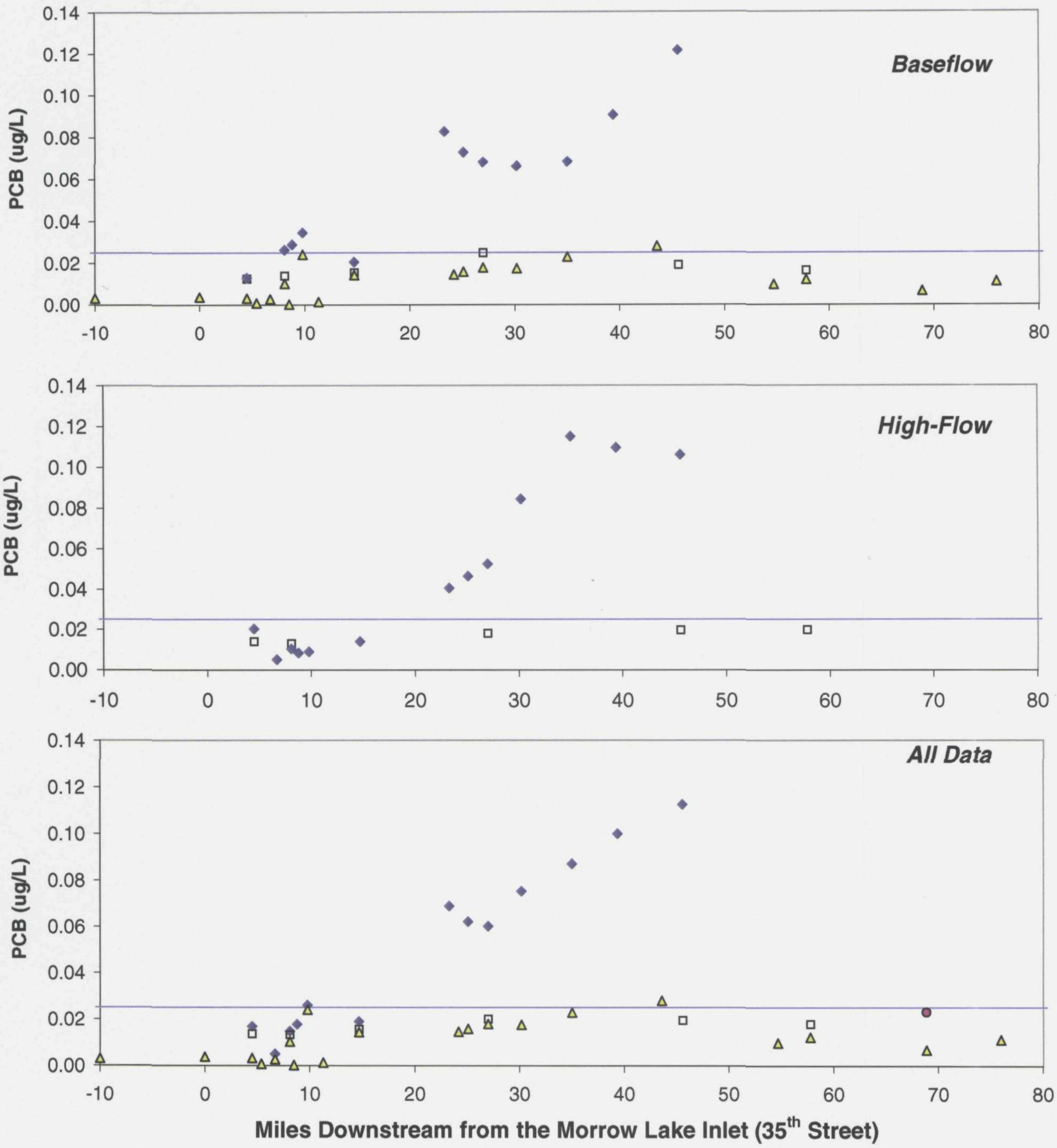
REMEDIAL INVESTIGATION REPORT

FREQUENCY DISTRIBUTION OF SILT AND CLAY IN 1993 FROZEN CORE AND FOCUSED CHANNEL SEDIMENT SAMPLES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-22

MJS_FOCUSED SEDIMENT.xls_4-22



LEGEND

- 1985-1988 Data
- 1994 Surface Water Investigation
- 1994-1995 Lake Michigan Mass Balance Study
- 1999-2000 CDM Data
- *Method Detection Limit (MDL) for 1994 data*

NOTES:

1. 1985-1988 data reported in the Description of the Current Situation (BBEPC, 1992).
2. Samples with no PCB detected were averaged as half the detection limit.
3. Dredging associated data collected at Farmer Street on August 5, 1994 are not included.
4. CDM 1999-2000 data were collected during low-flow or baseflow events.

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ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

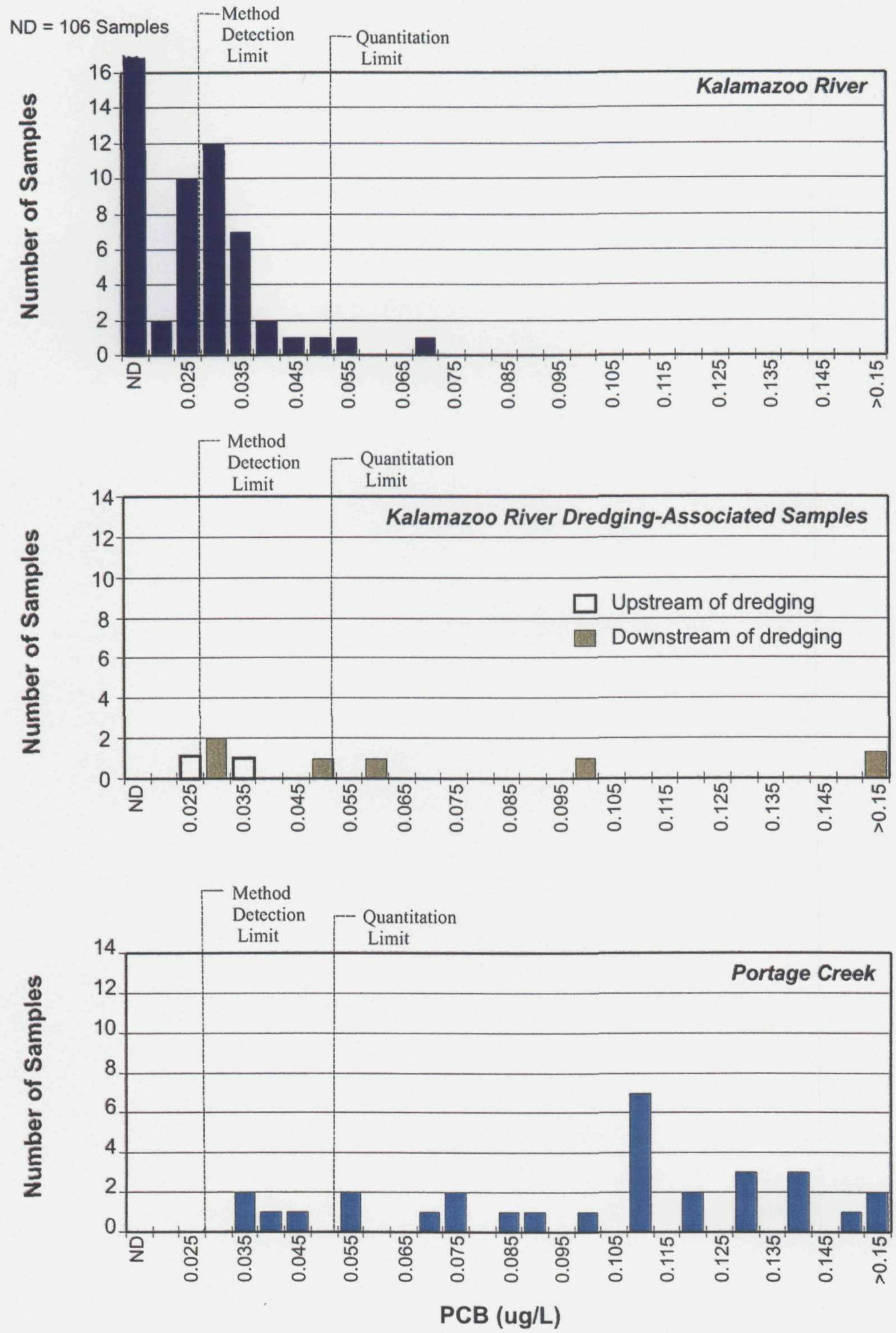
REMEDIAL INVESTIGATION REPORT

AVERAGE HISTORICAL AND CURRENT PCB CONCENTRATIONS IN KALAMAZOO RIVER SURFACE WATER SAMPLES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-23

MJS_SW PCB.xls_4-23



LEGEND

ND = Not Detected

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08/00 SYR-D54-DJH LBR LAS
64524500/64524n11.CDR

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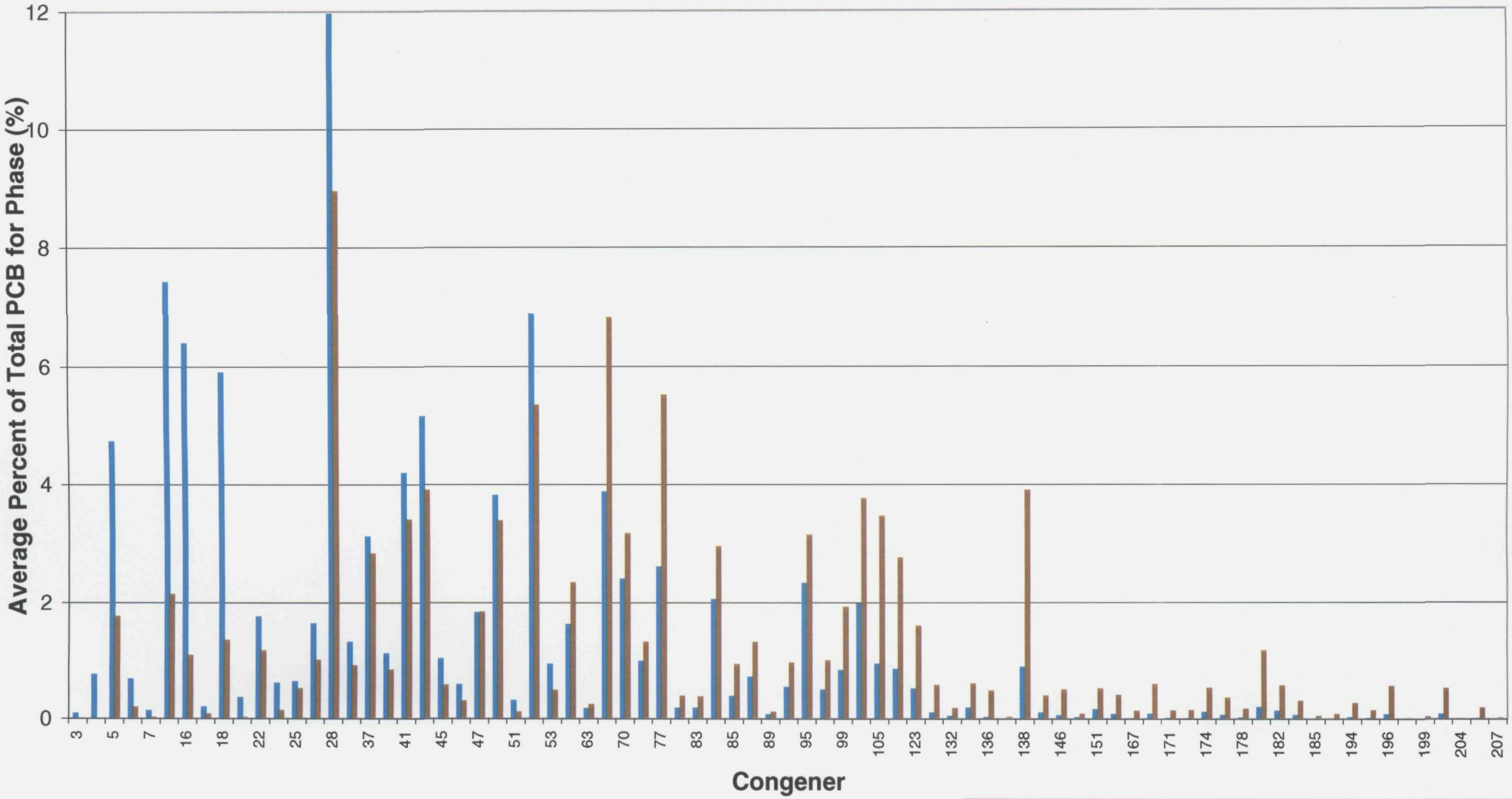
REMEDIAL INVESTIGATION REPORT

SUMMARY OF PCB DETECTION FREQUENCY IN 1994 KALAMAZOO RIVER AND PORTAGE CREEK SURFACE WATER SAMPLES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **4-24**



LEGEND

Dissolved-phase PCB

Particulate-phase PCB

Congeners identified by the BZ number (Ballschmiter and Zell, 1980)

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REMEDIAL INVESTIGATION REPORT

LAKE MICHIGAN MASS BALANCE DATA - COMPARISON OF CONGENER DISTRIBUTION FOR DISSOLVED AND PARTICULATE PHASE PCB

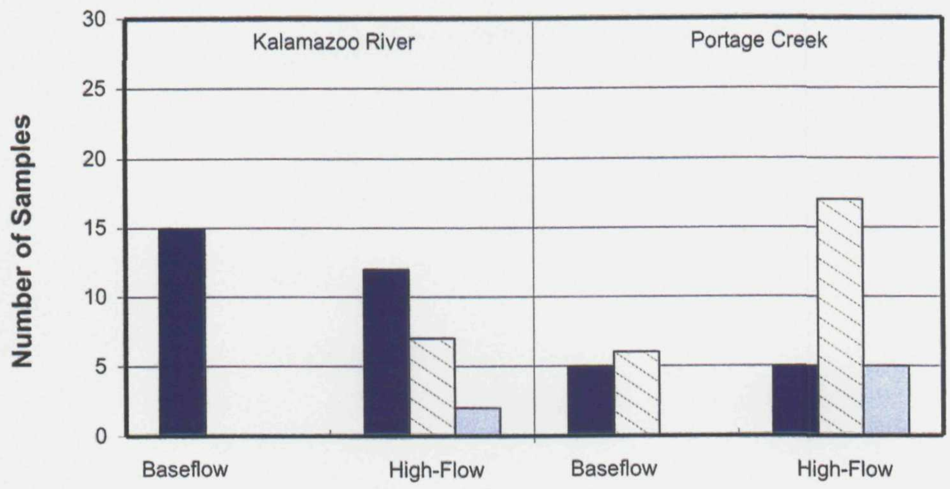
BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-25

MJS_LMICH.xls_4-25

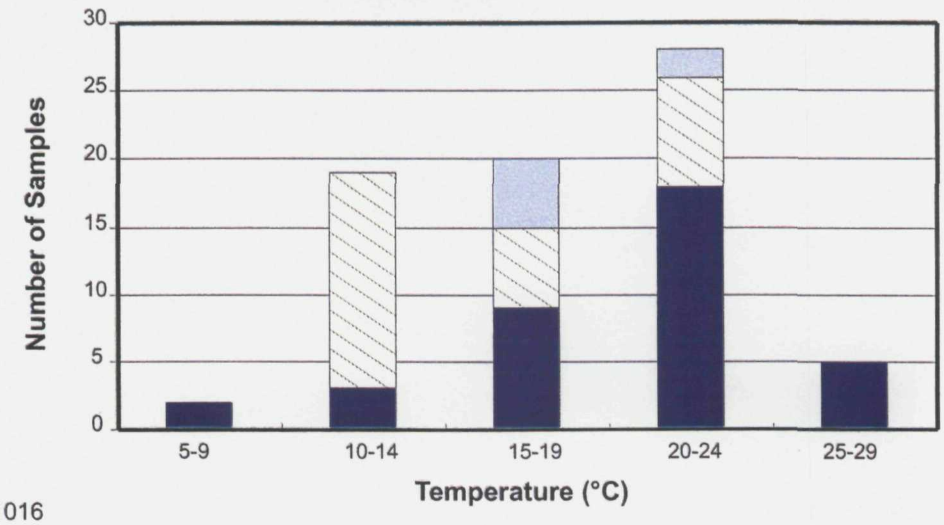
Aroclor Quantitation Frequency in Baseflow and High-Flow Samples

a)



Aroclor Quantitation Frequency by Temperature Interval

b)



LEGEND

- Aroclor 1016
- Aroclor 1242 (commonly assoc w/ paper recycling)
- Aroclor 1248

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NOTE:
The different degrees of chlorination are noted by four-digit numbers after the trade name Aroclor. The first two digits refer to the 12 carbons in biphenyl. For all Aroclors but one, the last two digits of the four-digit term represent the percentages of chlorination by mass of the PCB mixtures. The one exception is Aroclor 1016, which is 41% chlorinated.

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REMEDIAL INVESTIGATION REPORT

SUMMARY OF AROCLOR QUANTITATION FREQUENCY IN 1994 SURFACE WATER SAMPLES

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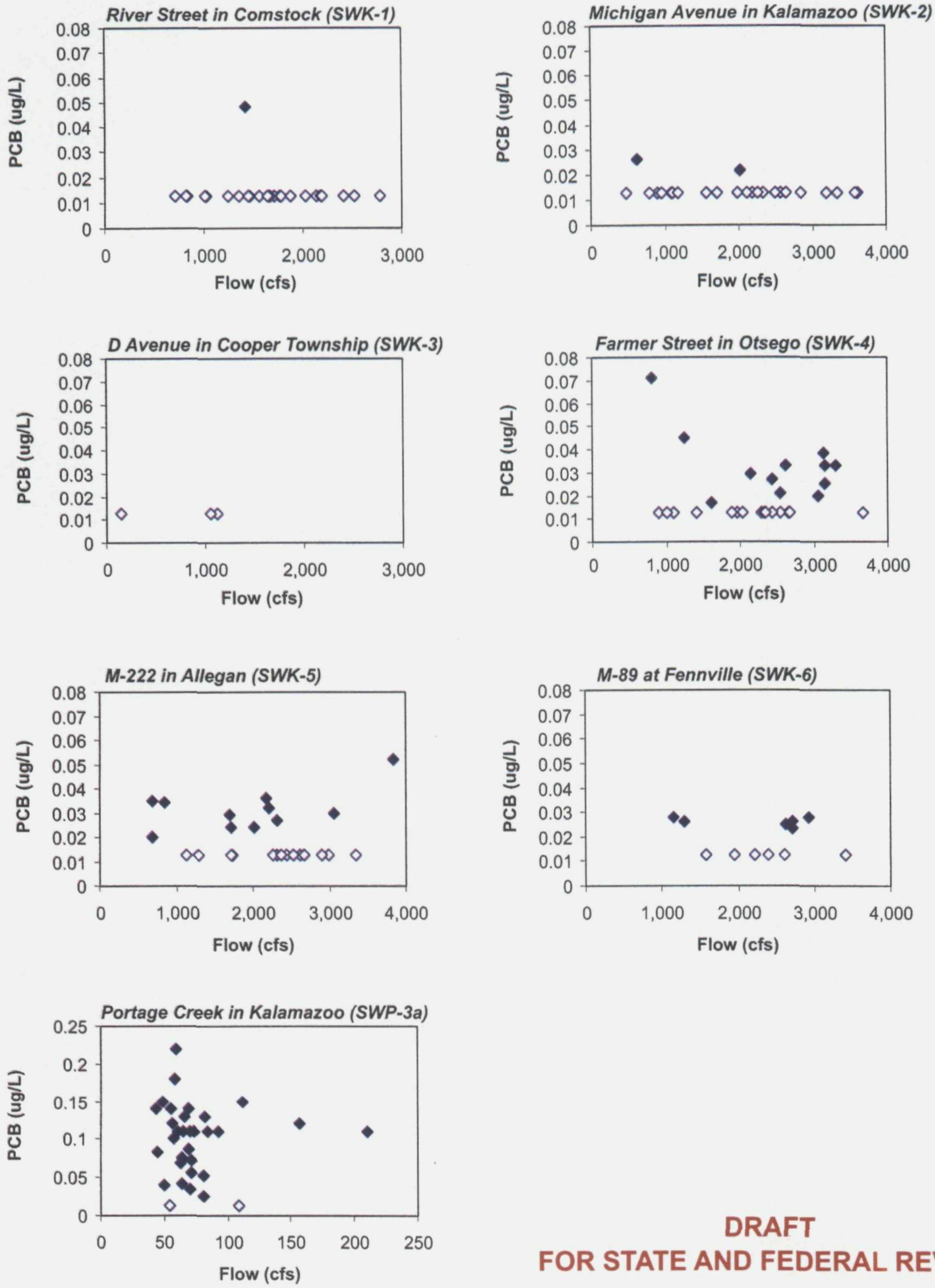
FIGURE **4-26**

10/00 SYR-D54-DJH, LBR, LAS
64524500/64524n04.CDR



LEGEND:

◆ PCB detected in sample

◇ PCB concentration reported as not detected

NOTE:

Dredging-associated samples collected at Farmer Street on August 5, 1994 are not included.

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ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

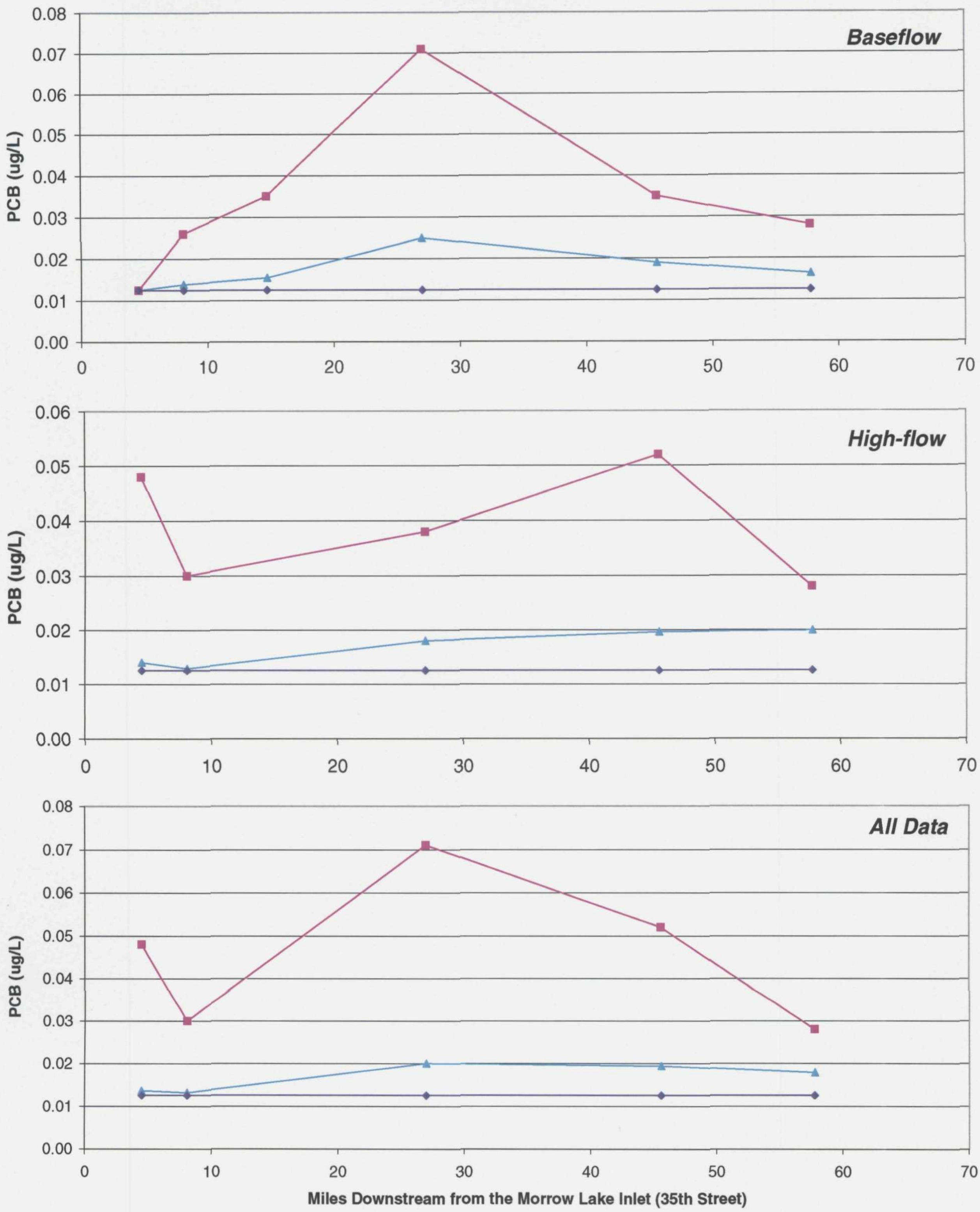
REMEDIAL INVESTIGATION REPORT

RELATIONSHIP OF PCB CONCENTRATION AND FLOW FOR 1994 KALAMAZOO RIVER AND PORTAGE CREEK SURFACE WATER SAMPLING LOCATIONS

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-27

10/00 SYR-D54-DJH LBR LAS
64524500/64524n10.CDR



LEGEND

- Average
- Maximum
- Minimum

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NOTES:

1. Portage Creek data are not included.
2. Samples with no PCB detected are averaged as half the method detection limit.
3. Dredging associated data collected at Farmer Street on August 5, 1994 are not included.

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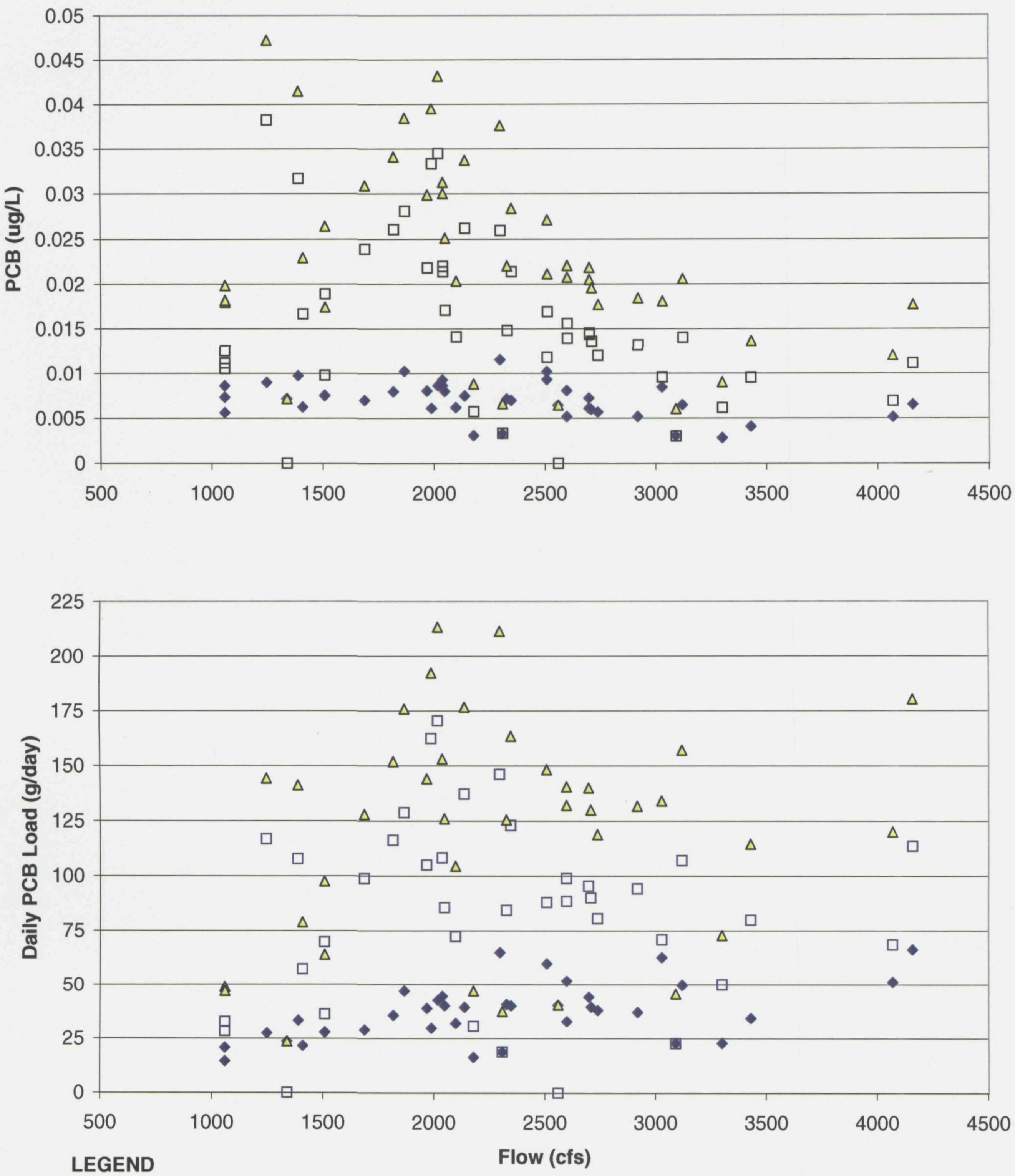
REMEDIAL INVESTIGATION REPORT

AVERAGE AND RANGE OF 1994 KALAMAZOO RIVER SURFACE WATER PCB CONCENTRATIONS

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 4-28

MJS_SW PCB.xls_4-28



LEGEND

◆ Dissolved-Phase PCB

□ Particulate-Phase PCB

△ Total PCB

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NOTE:
Data from the Lake Michigan Mass Balance Study, provided by USEPA (Warren, 1999).

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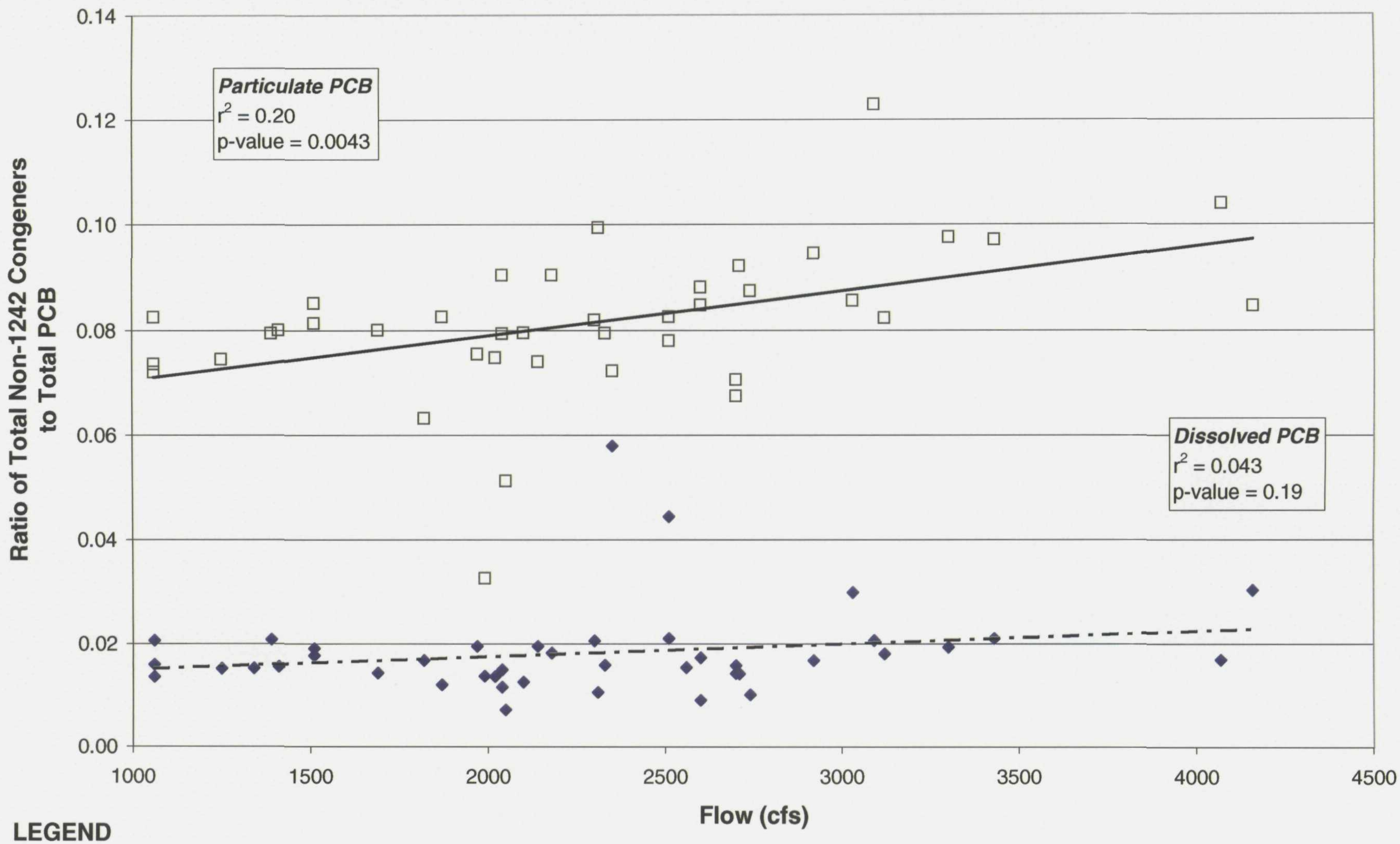
REMEDIAL INVESTIGATION REPORT

RELATIONSHIP OF PCB CONCENTRATION AND FLOW NEAR NEW RICHMOND

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-29

MJS_LMICH.xls_4-29



LEGEND

- ◆ Dissolved-Phase PCB
- □ Particulate-Phase PCB
- —— Linear Regression Line - Particulate-Phase PCB
- – · – Linear Regression Line - Dissolved-Phase PCB

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NOTE:
Data from the Lake Michigan Mass Balance Study, provided by USEPA (Warren, 1999).

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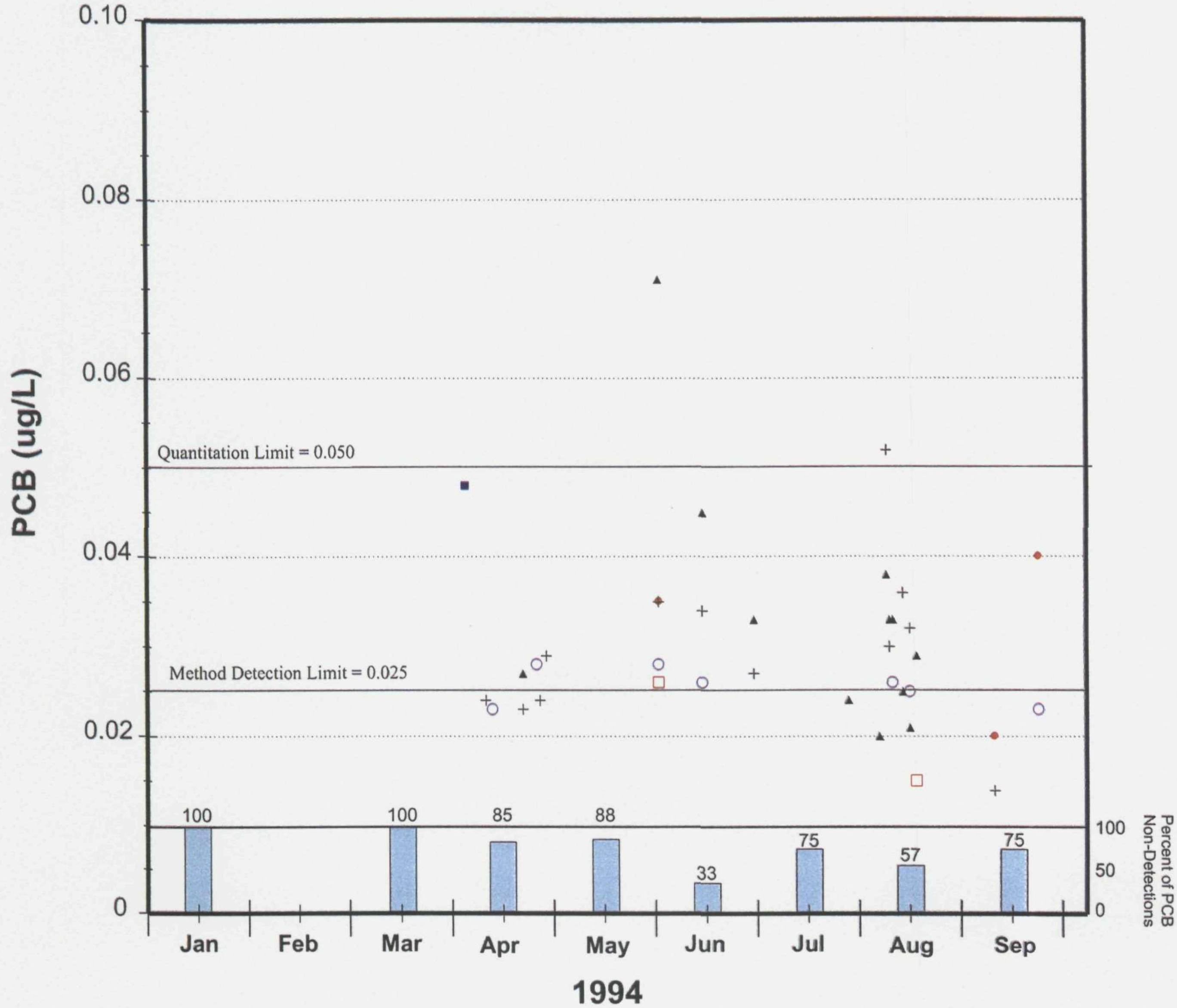
REMEDIAL INVESTIGATION REPORT

RELATIONSHIP OF RELATIVE NON-AROCLOR 1242 CONCENTRATIONS AND FLOW NEAR NEW RICHMOND

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-30

DMP_LakeMI.xls_4-30



LEGEND

- ■ SWK-1 - River Street
- □ SWK-2 - Michigan Avenue
- ● SWK-3 - D Avenue
- ▲ SWK-4 - Farmer Street
- + SWK-5 - Highway M222
- ○ SWK-6 - Highway M89

NOTE:

Dredging-associated data from SWK-4 not included.

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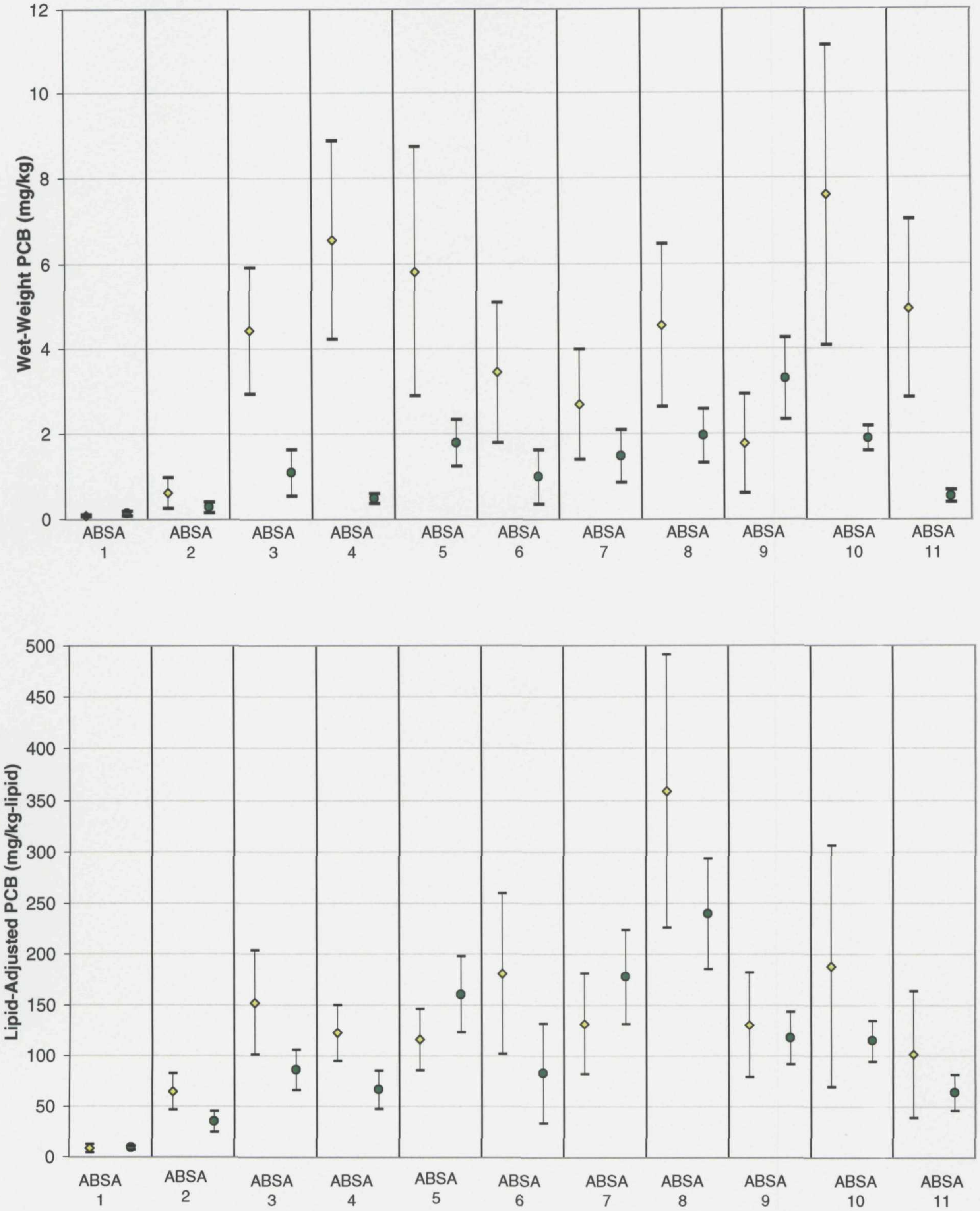
REMEDIAL INVESTIGATION REPORT

DETECTED PCB CONCENTRATIONS IN 1994 KALAMAZOO RIVER SURFACE WATER SAMPLES

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-31

08/00 SYR-D54-DJH LBR LAS
64524500/64524n06.CDR



LEGEND

◆ Carp fillets

● Smallmouth bass fillets

Upper 95% confidence limit
Arithmetic Mean Concentration
Lower 95% confidence limit

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ABSA 1 - Battle Creek
ABSA 2 - Morrow Lake
ABSA 3 - Upstream of Portage Creek
ABSA 4 - Near Mosel Ave in Kalamazoo
ABSA 5 - Former Plainwell Impoundment
ABSA 6 - Otsego City Impoundment
ABSA 7 - Former Otsego Impoundment
ABSA 8 - Former Trowbridge Impoundment
ABSA 9 - Lake Allegan
ABSA 10 - Swan Creek Marsh
ABSA 11 - New Richmond

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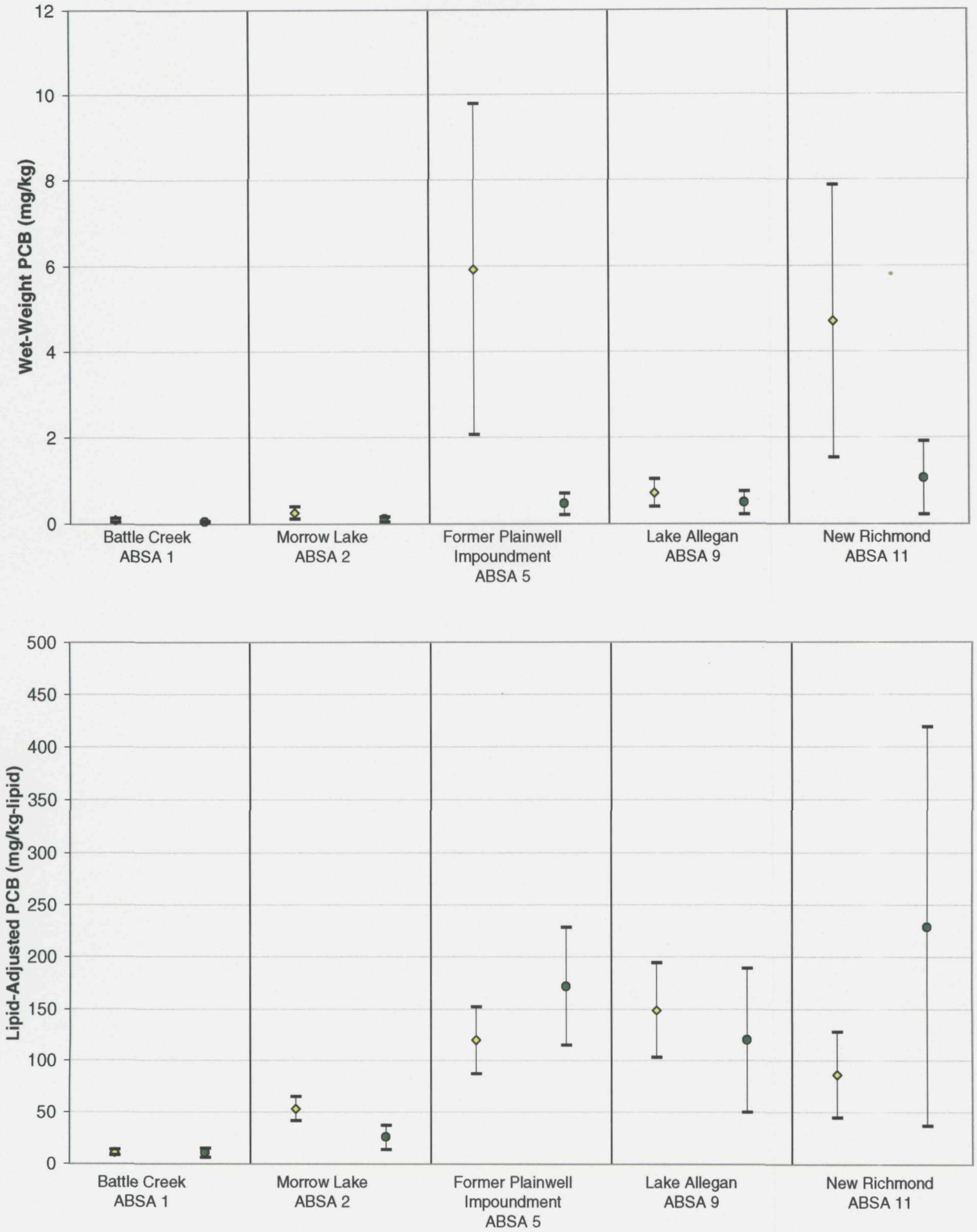
REMEDIAL INVESTIGATION REPORT

MEAN WET-WEIGHT AND LIPID-ADJUSTED PCB CONCENTRATION IN SMALLMOUTH BASS AND CARP - 1993

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 4-32

MJS_Fish93-99.xls_4-32



LEGEND

◆ Carp fillets

● Smallmouth bass fillets

Upper 95% confidence limit
Arithmetic Mean Concentration
Lower 95% confidence limit

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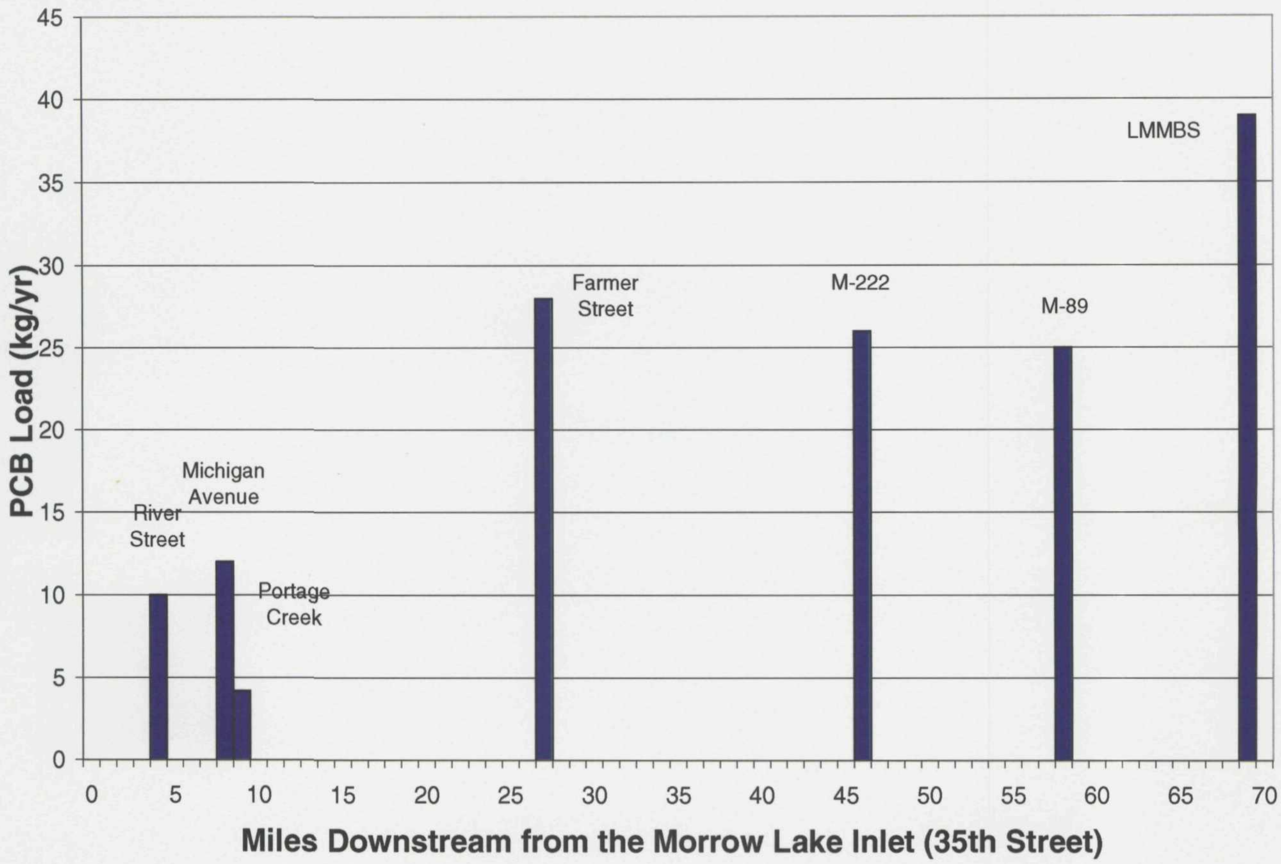
REMEDIAL INVESTIGATION REPORT

MEAN WET-WEIGHT AND LIPID-ADJUSTED PCB CONCENTRATION IN SMALLMOUTH BASS AND CARP - 1997

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 4-33

MJS_Fish93-99.xls_4-33



NOTES:

1. Annual PCB loads calculated using a flow-stratified method and summarized in Table 5-1.
2. Data from D Avenue (SWK-3) are not included.

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KALAMAZOO RIVER STUDY GROUP
ALLIED PAPER, INC./PORTAGE CREEK/KALAMAZOO RIVER SUPERFUND SITE

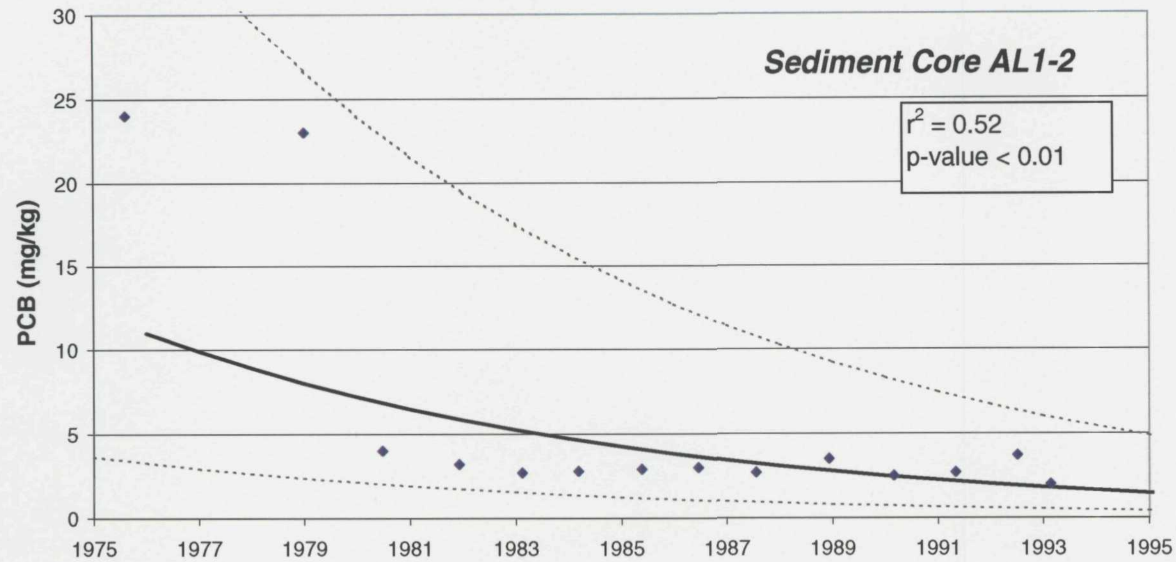
REMEDIAL INVESTIGATION REPORT

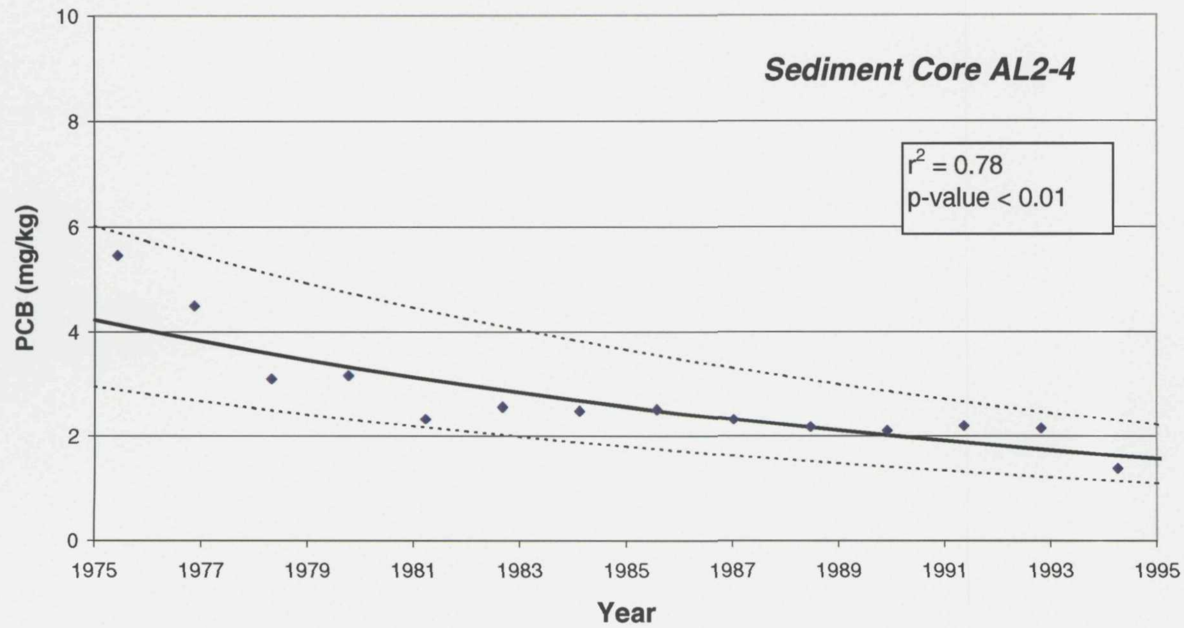
ESTIMATED ANNUAL PCB LOAD IN THE KALAMAZOO RIVER AND PORTAGE CREEK - 1994 DATA

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 5-1

MJS_Stratified.xls_5-1





LEGEND

------- 95% confidence interval
——— PCB Trend

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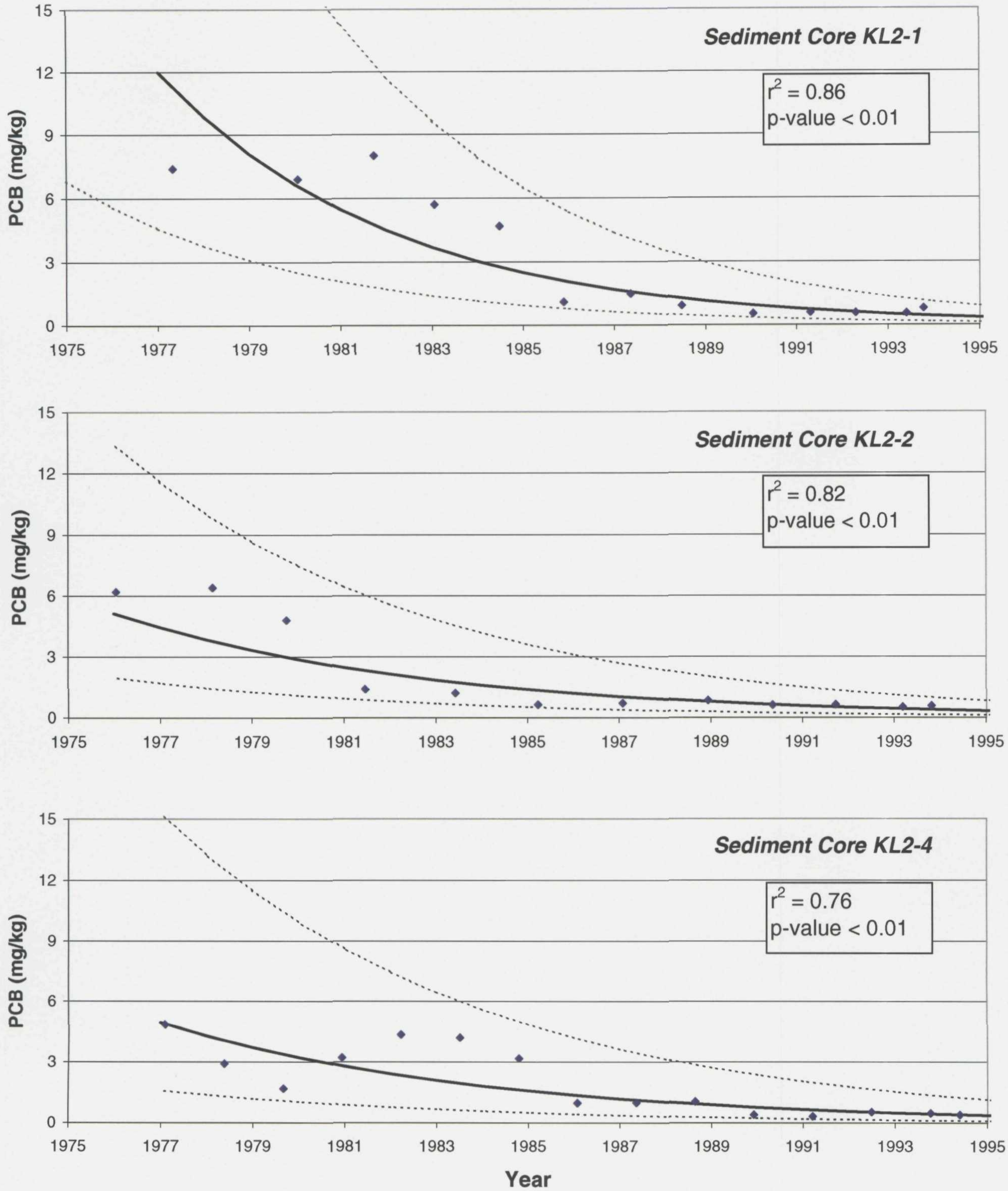
REMEDIAL INVESTIGATION REPORT

PCB TRENDS IN ALLEGAN CITY IMPOUNDMENT SEDIMENT

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 5-2

MJS_NRFGS.xls_5-2



LEGEND

------- 95 % confidence interval

——— PCB Trend

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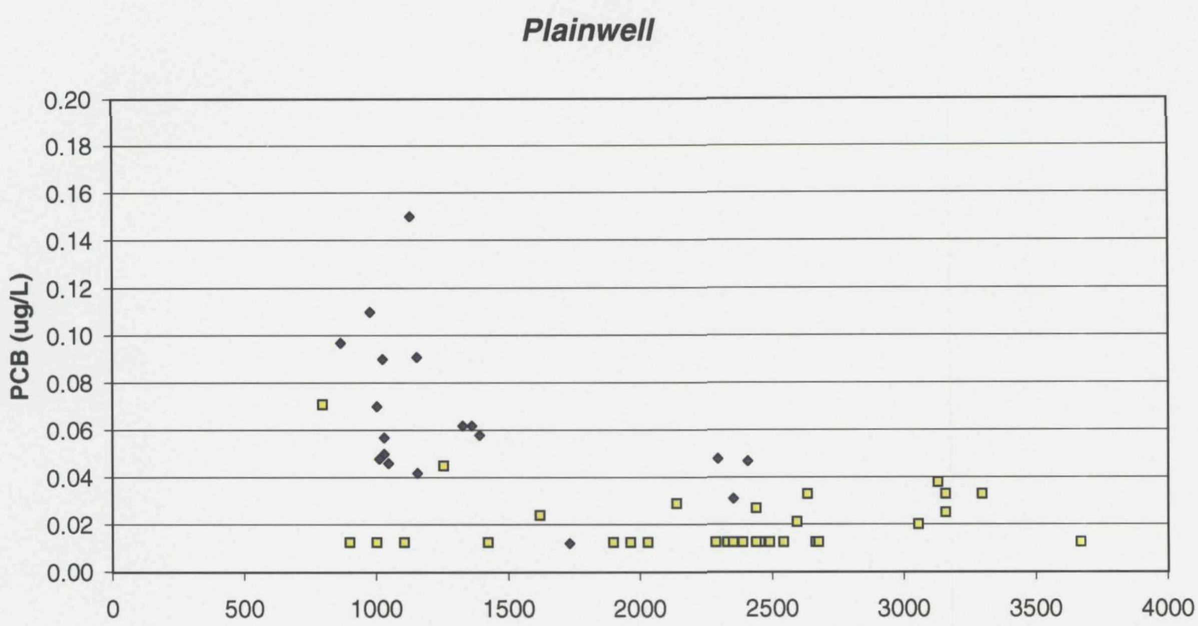
REMEDIAL INVESTIGATION REPORT

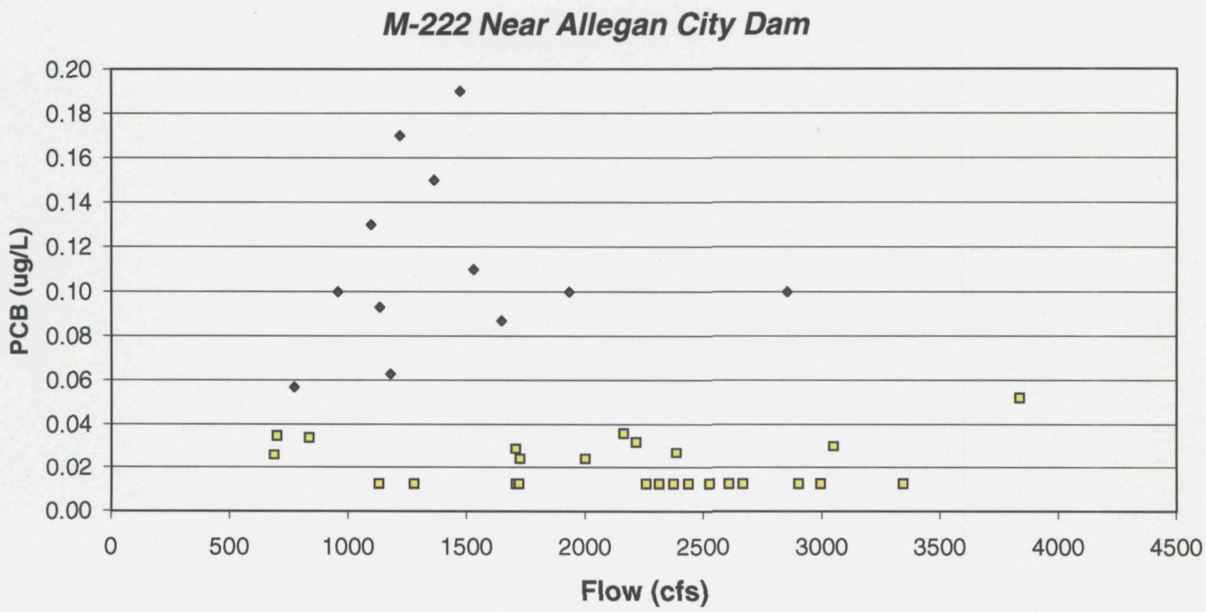
PCB TRENDS IN KALAMAZOO LAKE SEDIMENT

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 5-3

MJS_NRFGS.xls_5-3





LEGEND

◆ 1985-1988 Data

□ 1994 Data

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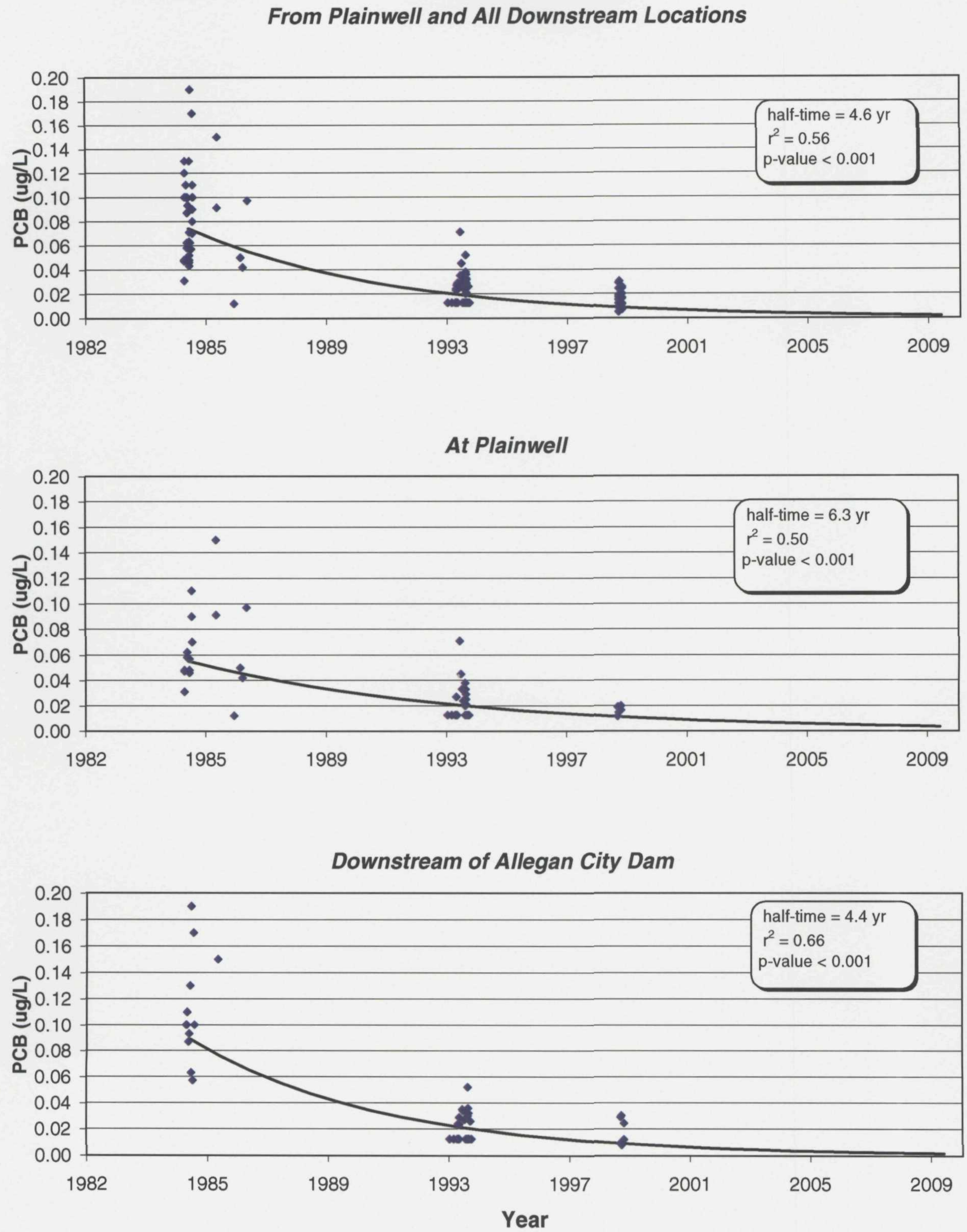
REMEDIAL INVESTIGATION REPORT

PCB LEVELS IN WATER SAMPLES IN RELATION TO RIVER FLOW

BBL BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 5-4

MJS_H2OTREND.xls_5-4



LEGEND

— PCB Trend

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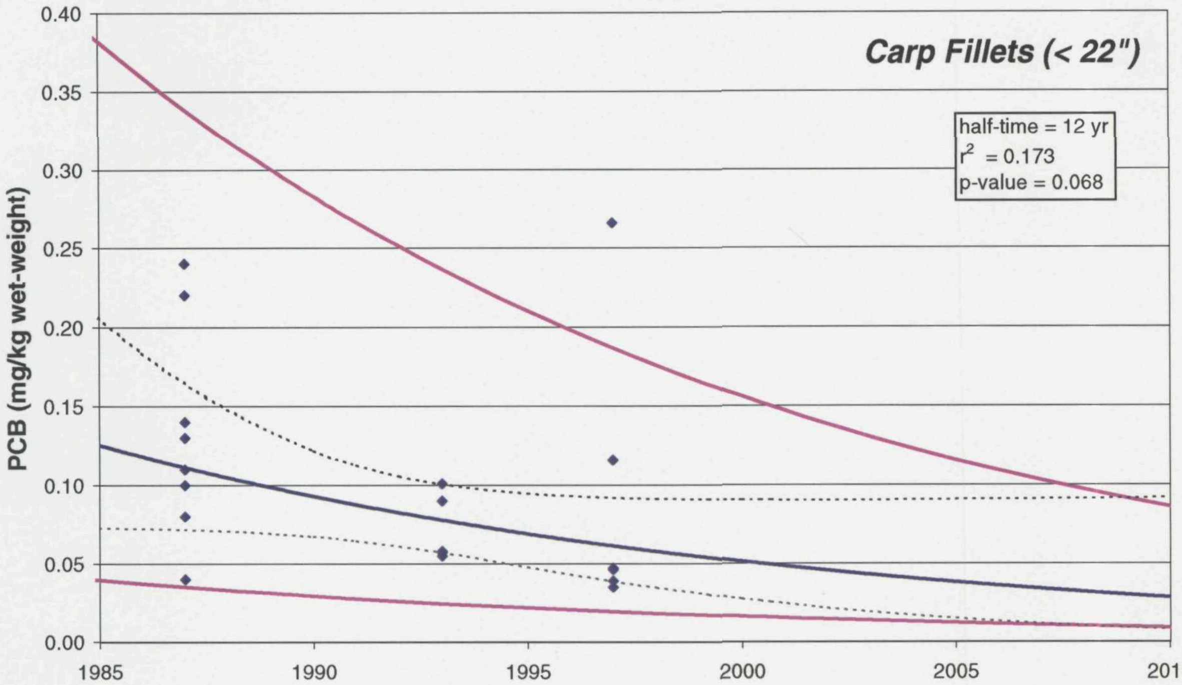
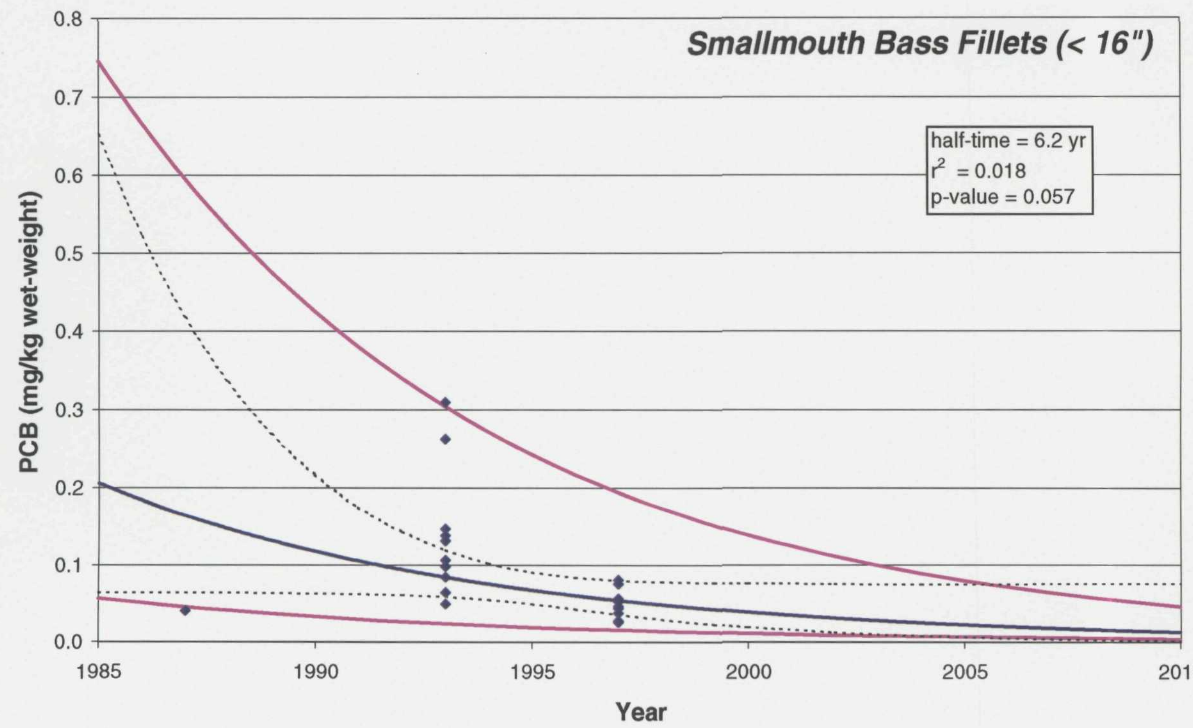
REMEDIAL INVESTIGATION REPORT

PCB TRENDS IN KALAMAZOO RIVER SURFACE WATER

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 5-5





LEGEND

- - - - - - 95% regression confidence interval
——— PCB Trend
——— 95% population confidence interval

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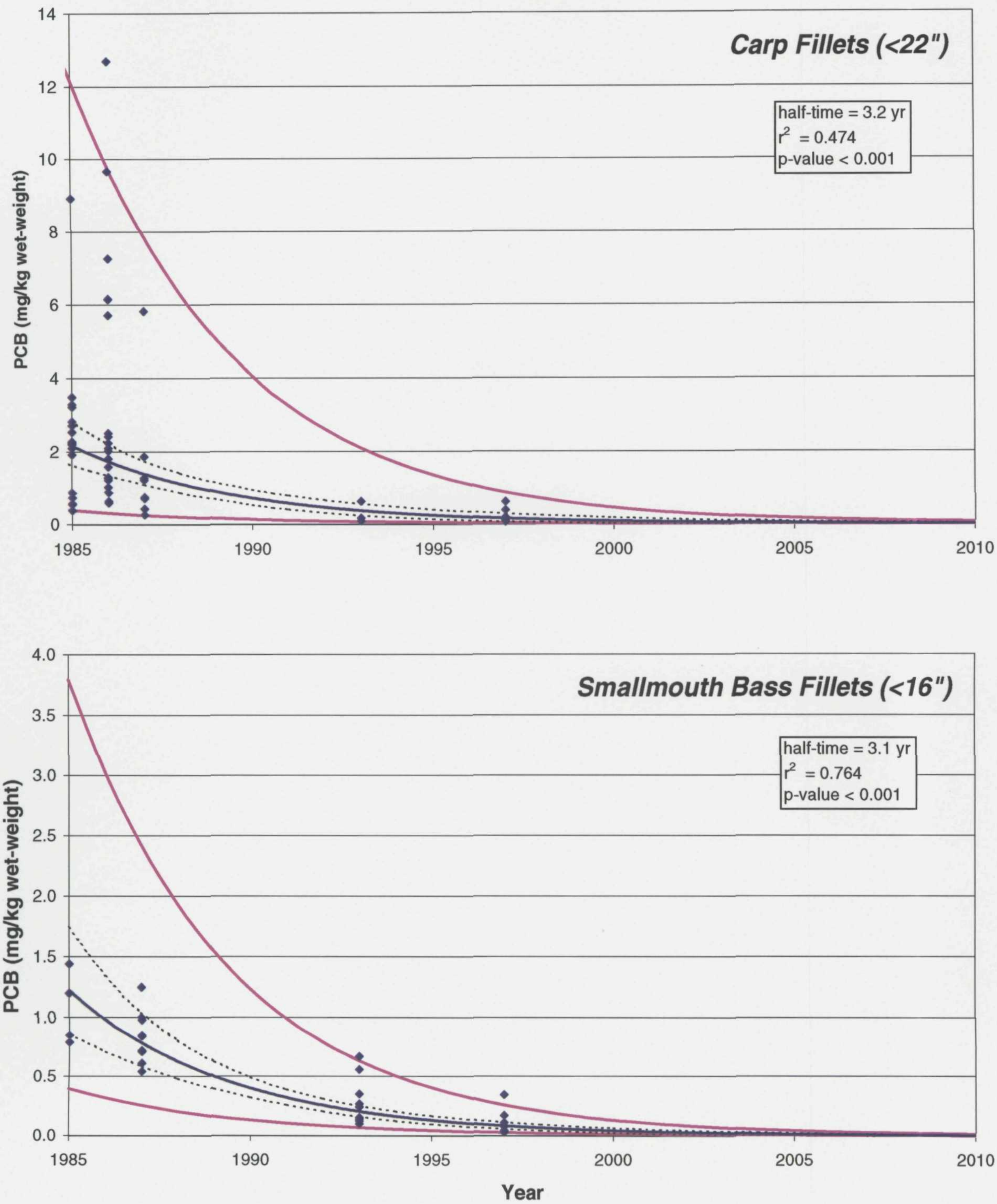
REMEDIAL INVESTIGATION REPORT

PCB TRENDS IN KALAMAZOO RIVER FISH NEAR BATTLE CREEK

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 5-6

MJS_New RI fish figs.xls_BATTLE CREEK



LEGEND

- - - - - - 95% regression confidence interval
——— PCB Trend
——— 95% population confidence interval

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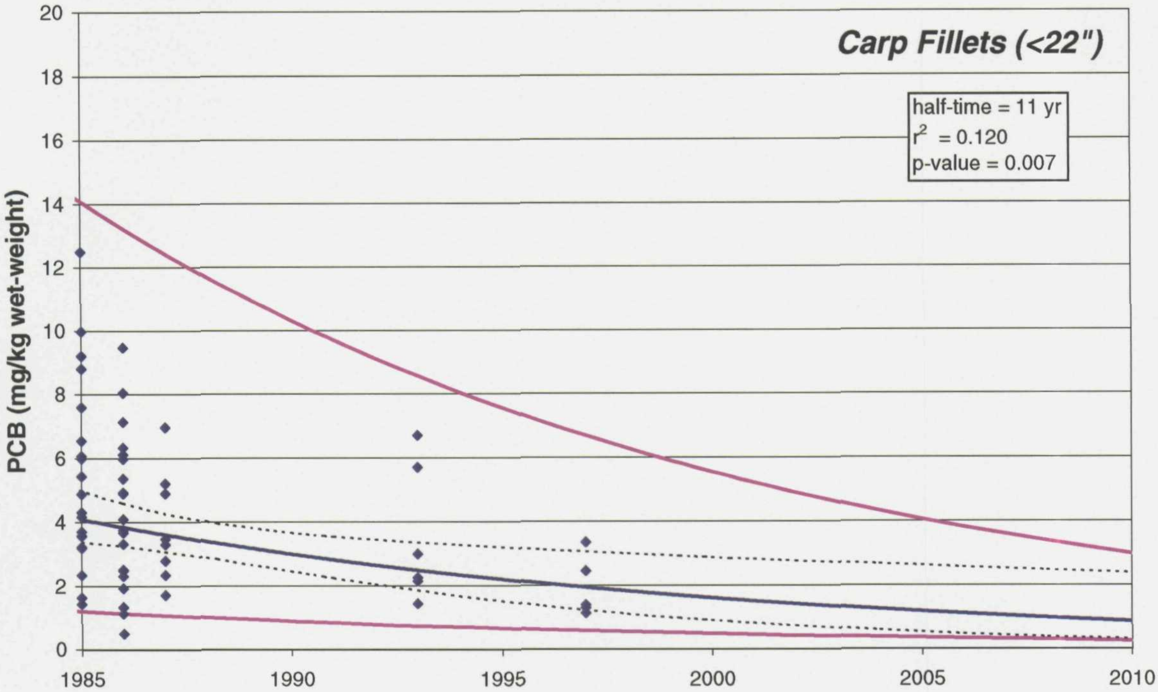
REMEDIAL INVESTIGATION REPORT

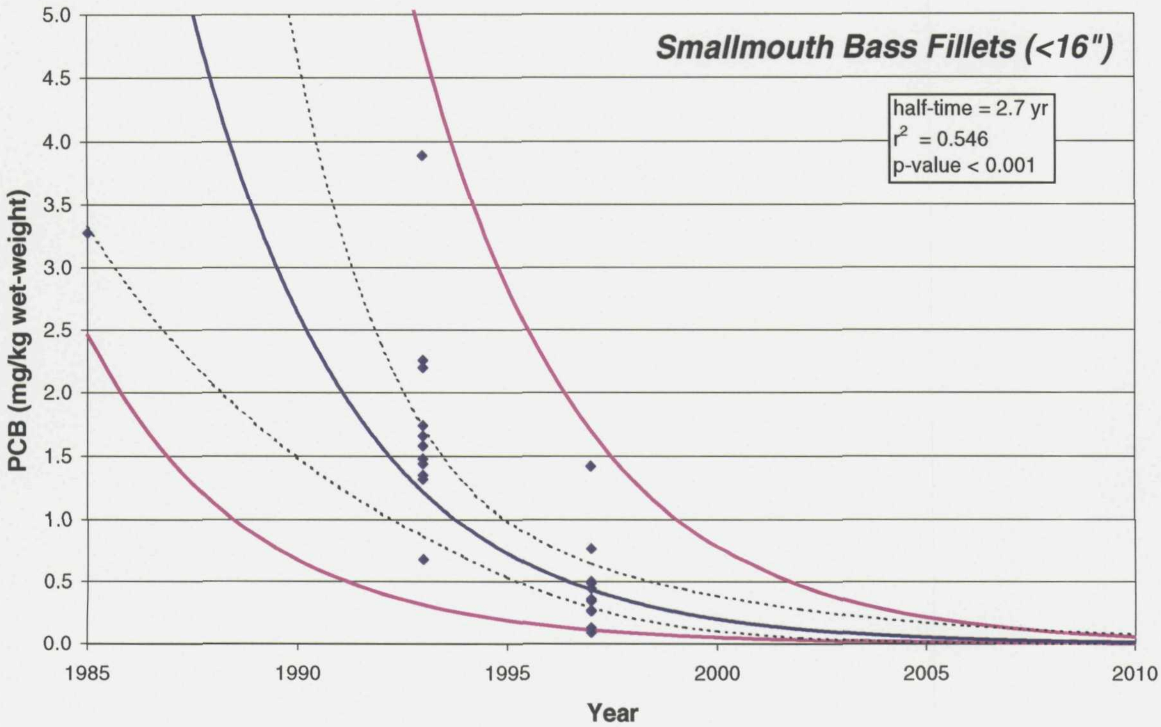
PCB TRENDS IN MORROW LAKE FISH

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 5-7

MJS_New RI fish figs.xls_MORROW LAKE





LEGEND

- - - - - - 95% regression confidence interval

——— PCB Trend

——— 95% population confidence interval

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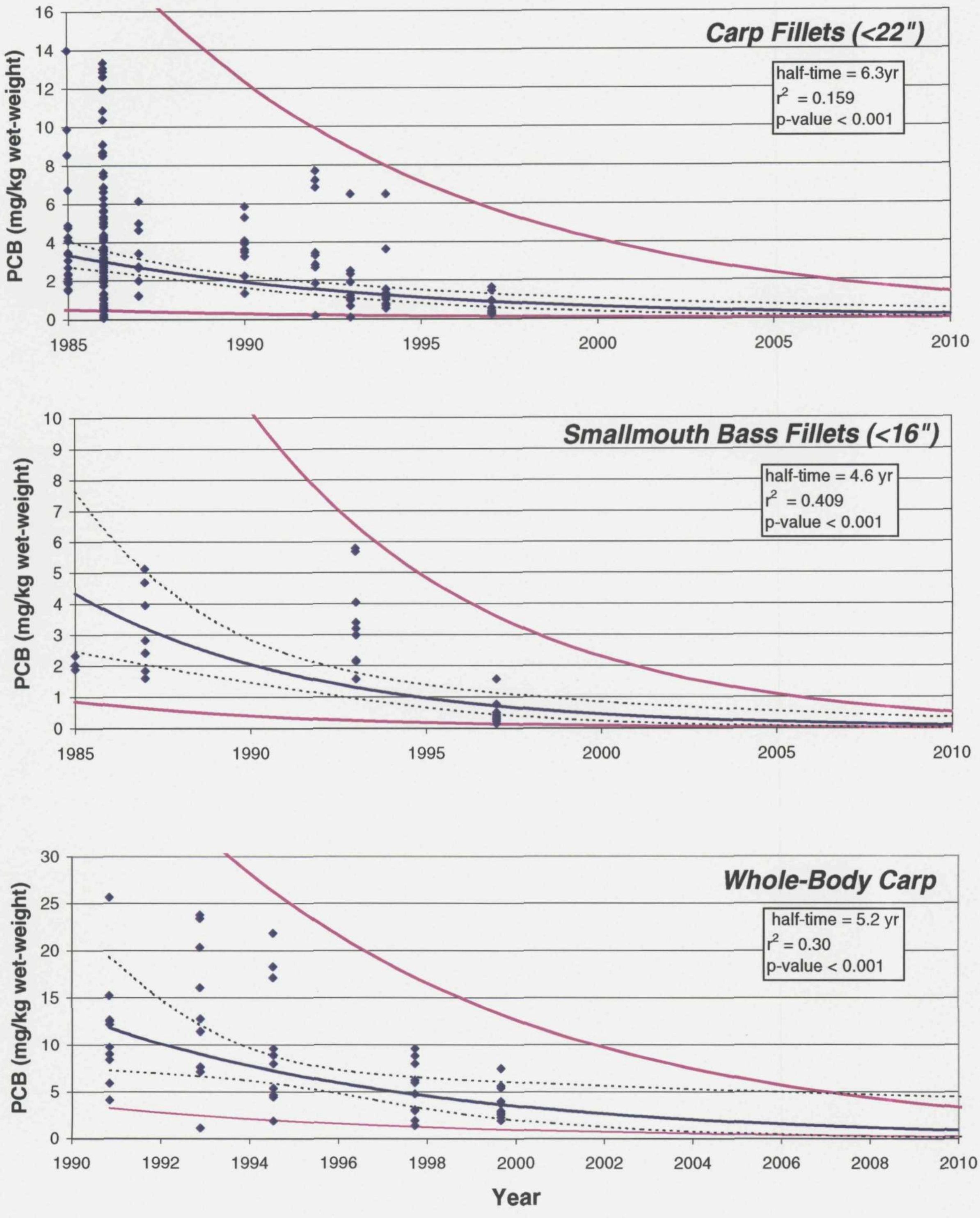
REMEDIAL INVESTIGATION REPORT

PCB TRENDS IN PLAINWELL IMPOUNDMENT FISH

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 5-8

MJS_New RI fish figs.xls_PLAINWELL



LEGEND

- - - - - - 95% regression confidence interval

——— PCB Trend

——— 95% population confidence interval

NOTES:

Lake Allegan whole-body carp PCB data based on 1990-99 MDEQ data.

Regression lines, half-times, and confidence intervals do not include 1999 KRSG results

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REMEDIAL INVESTIGATION REPORT

PCB TRENDS IN LAKE ALLEGAN FISH

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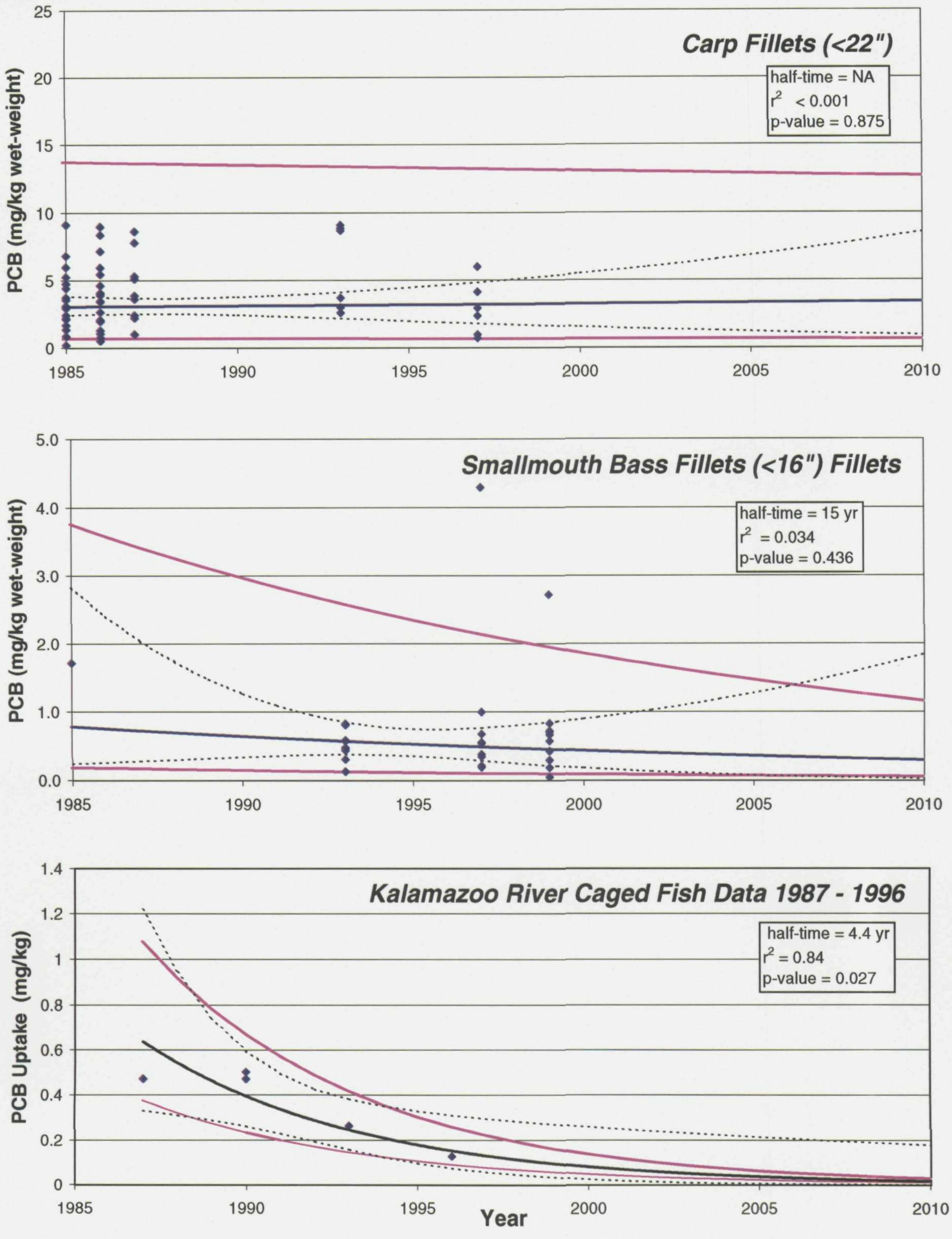
FIGURE 5-9



LEGEND

------ 95% regression confidence interval

—— PCB Trend

—— 95% population confidence interval

NOTE:
Caged fish PCB data based on MDEQ data collected near Saugatuck.

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REMEDIAL INVESTIGATION REPORT

PCB TRENDS IN KALAMAZOO RIVER FISH DOWNSTREAM OF LAKE ALLEGAN

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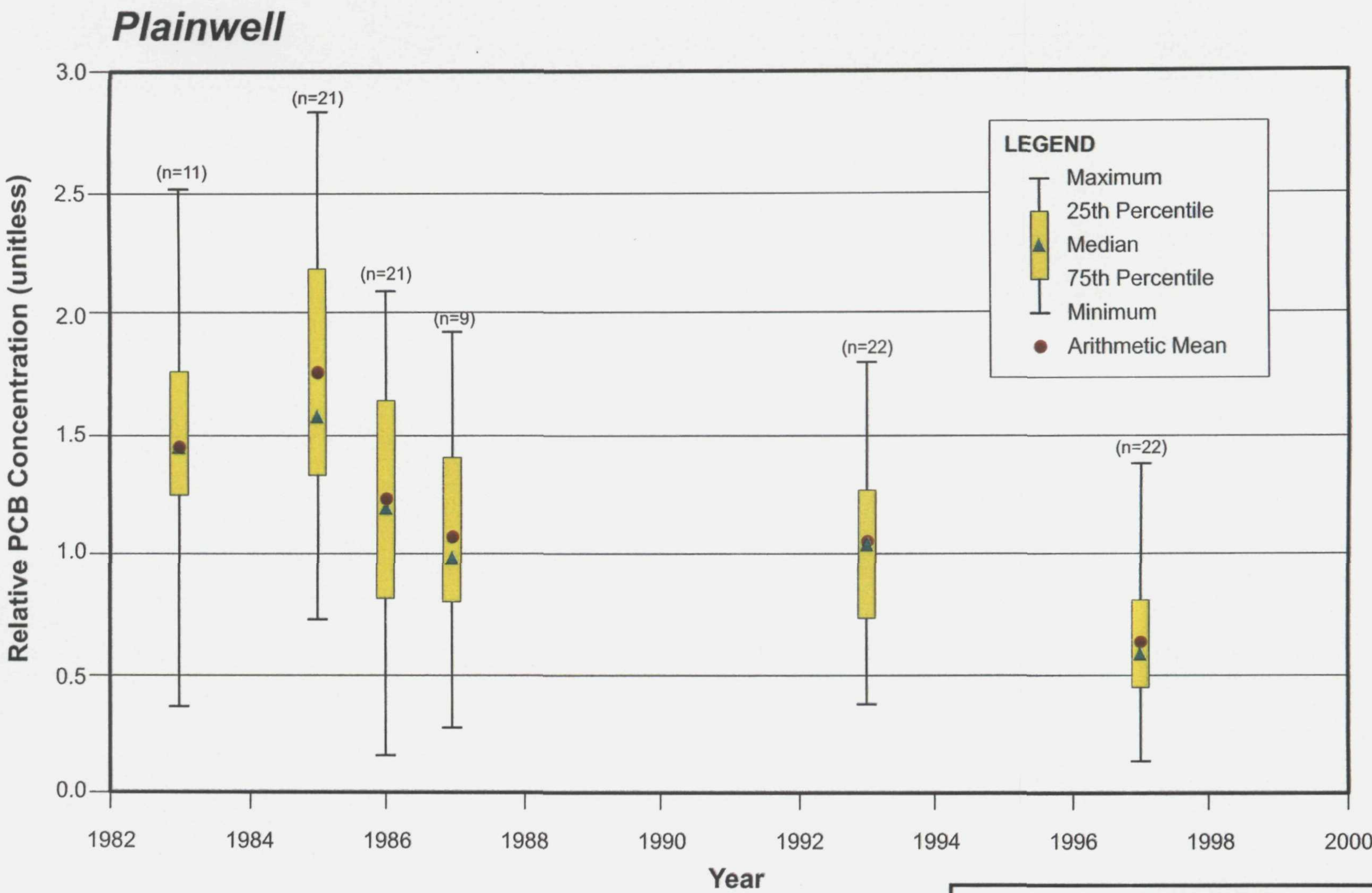
FIGURE 5-10



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REMEDIAL INVESTIGATION REPORT

RELATIVE PCB CONCENTRATION IN FISH - PLAINWELL DAM AREA

BLASLAND, BOUCK & LEE, INC.
engineers & scientists

FIGURE 5-11

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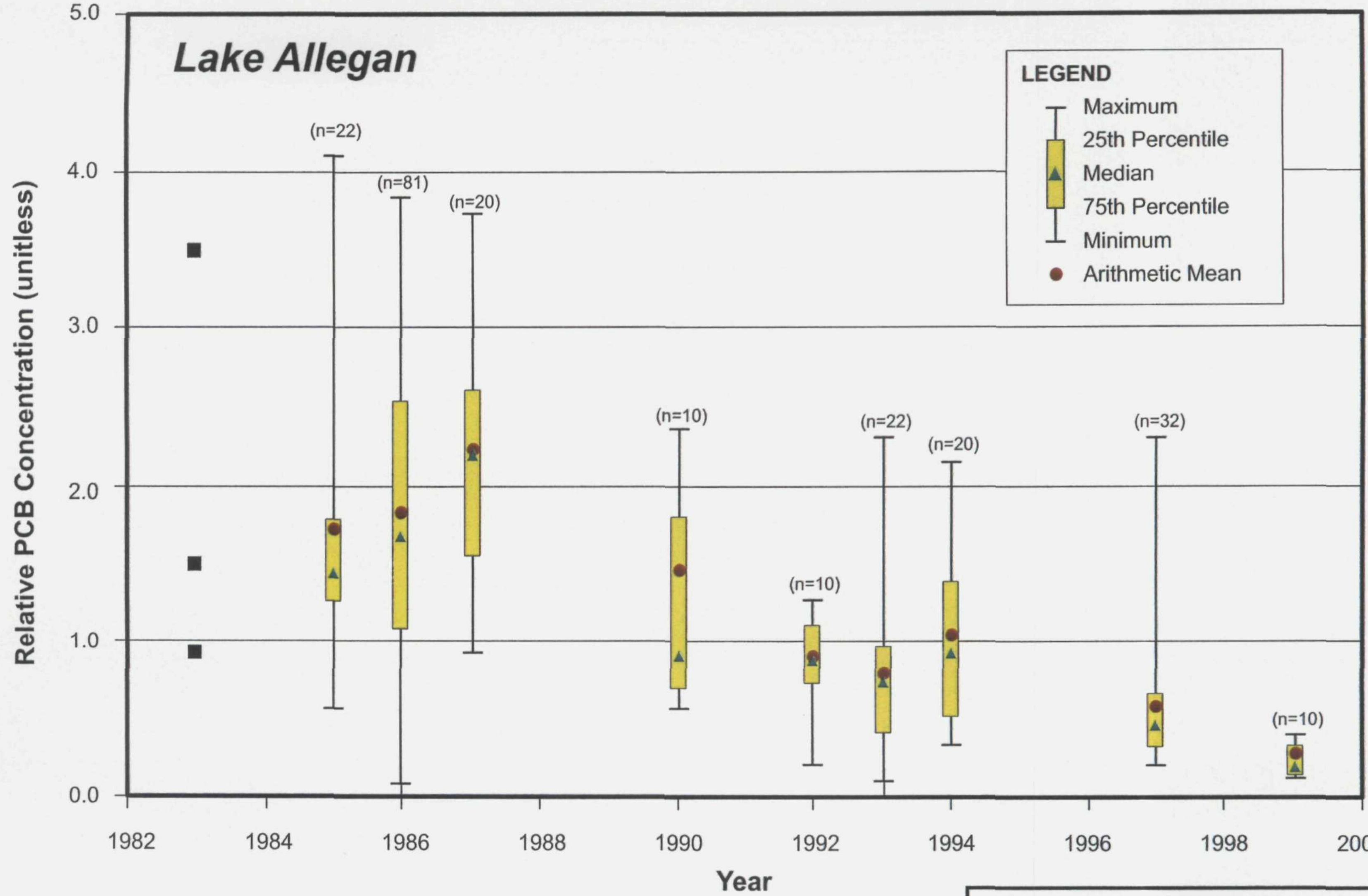
10/00 SYR-D54-DJH LAS
64524500/64524n56.CDR



NOTE:
1999 data based on MDEQ whole body carp samples

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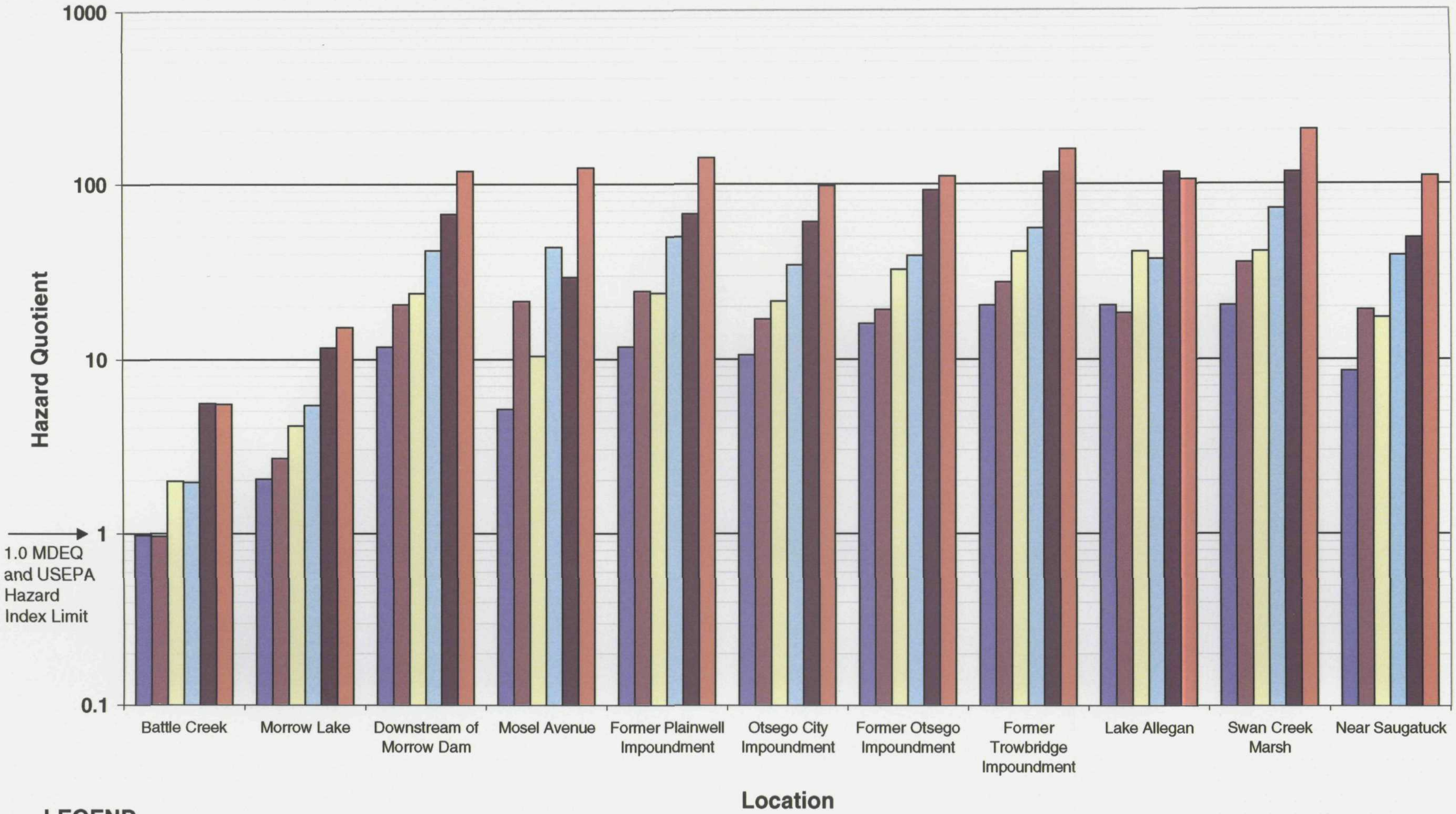
REMEDIAL INVESTIGATION REPORT

RELATIVE PCB CONCENTRATION IN FISH - LAKE ALLEGAN AREA

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE **5-12**

10/00 SYR-D54-DJH LAS
64524500/64524n55.CDR



LEGEND

- Sport Angler-Bass (Central Tendency)
- Sport Angler-Bass/Carp (Central Tendency)
- Sport Angler-Bass (High End)
- Sport Angler-Bass/Carp (High End)
- Subsistence Angler-Bass
- Subsistence Angler-Bass/Carp

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Estimates are those made by CDM (2000b) for all locations except Battle Creek and Morrow Lake. Battle Creek and Morrow Lake estimates were made by scaling average fish PCB concentrations.

KALAMAZOO RIVER STUDY GROUP
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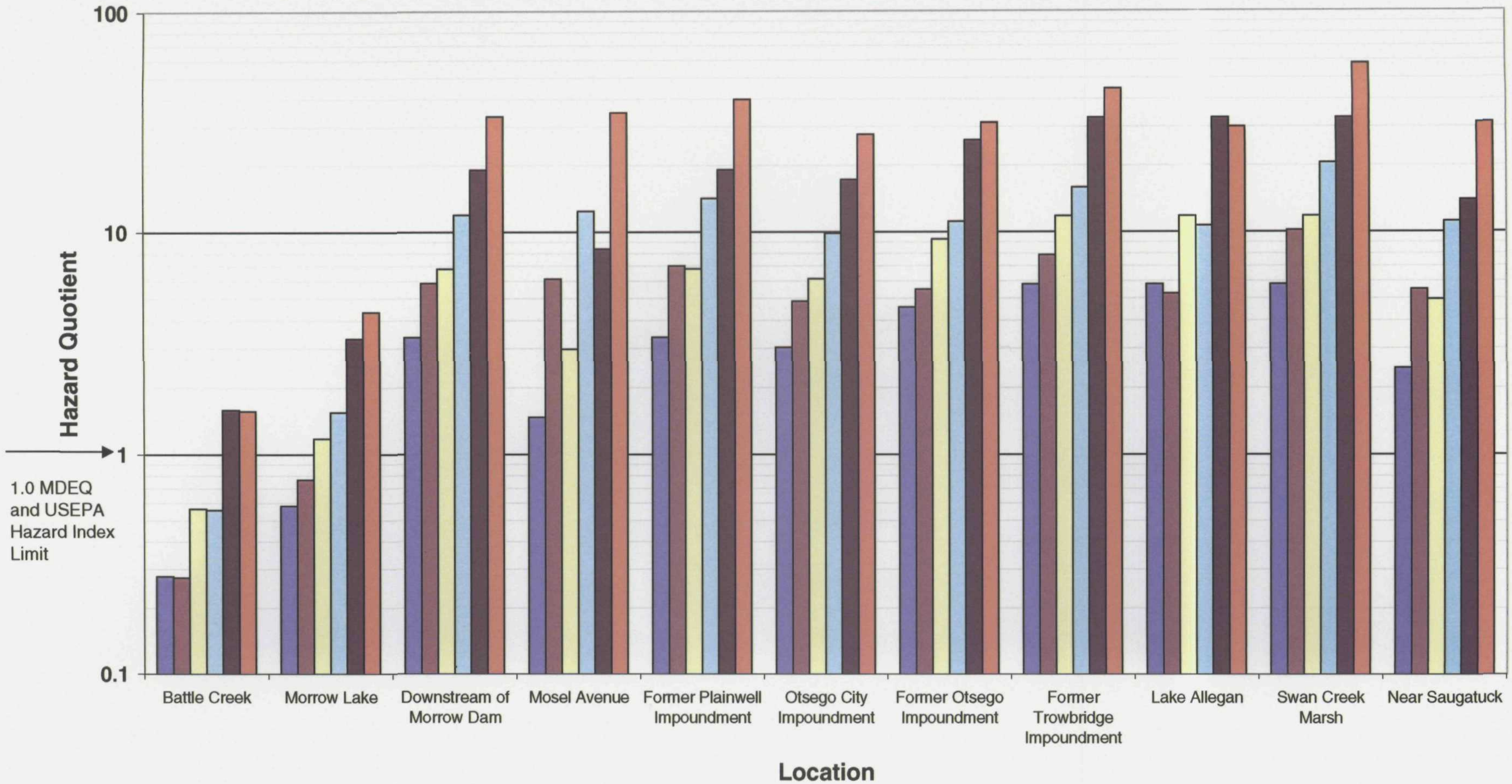
REMEDIAL INVESTIGATION REPORT

IMMUNOLOGICAL HAZARD QUOTIENTS FOR ABSAS BASED ON AVERAGE PCB CONCENTRATIONS

BBL BLASLAND, BOUCK & LEE, INC. *engineers & scientists*

FIGURE 6-1

MJS_RevHHRAfigs.xls_6-1



LEGEND

- Sport Angler-Bass (Central Tendency)
- Sport Angler-Bass/Carp (Central Tendency)
- Sport Angler-Bass (High End)
- Sport Angler-Bass/Carp (High End)
- Subsistence Angler-Bass
- Subsistence Angler-Bass/Carp

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Estimates are those made by CDM (2000b) for all locations except Battle Creek and Morrow Lake. Battle Creek and Morrow Lake estimates were made by scaling average fish PCB concentrations.

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REMEDIAL INVESTIGATION REPORT

REPRODUCTIVE HAZARD QUOTIENTS FOR ABSAS BASED ON AVERAGE PCB CONCENTRATIONS

BBL BLASLAND, BOUCK & LEE, INC. engineers & scientists

FIGURE 6-2

MJS_RevHHRAfigs.xls_6-2